CHAPTER 3

The Cellular Level of Organization

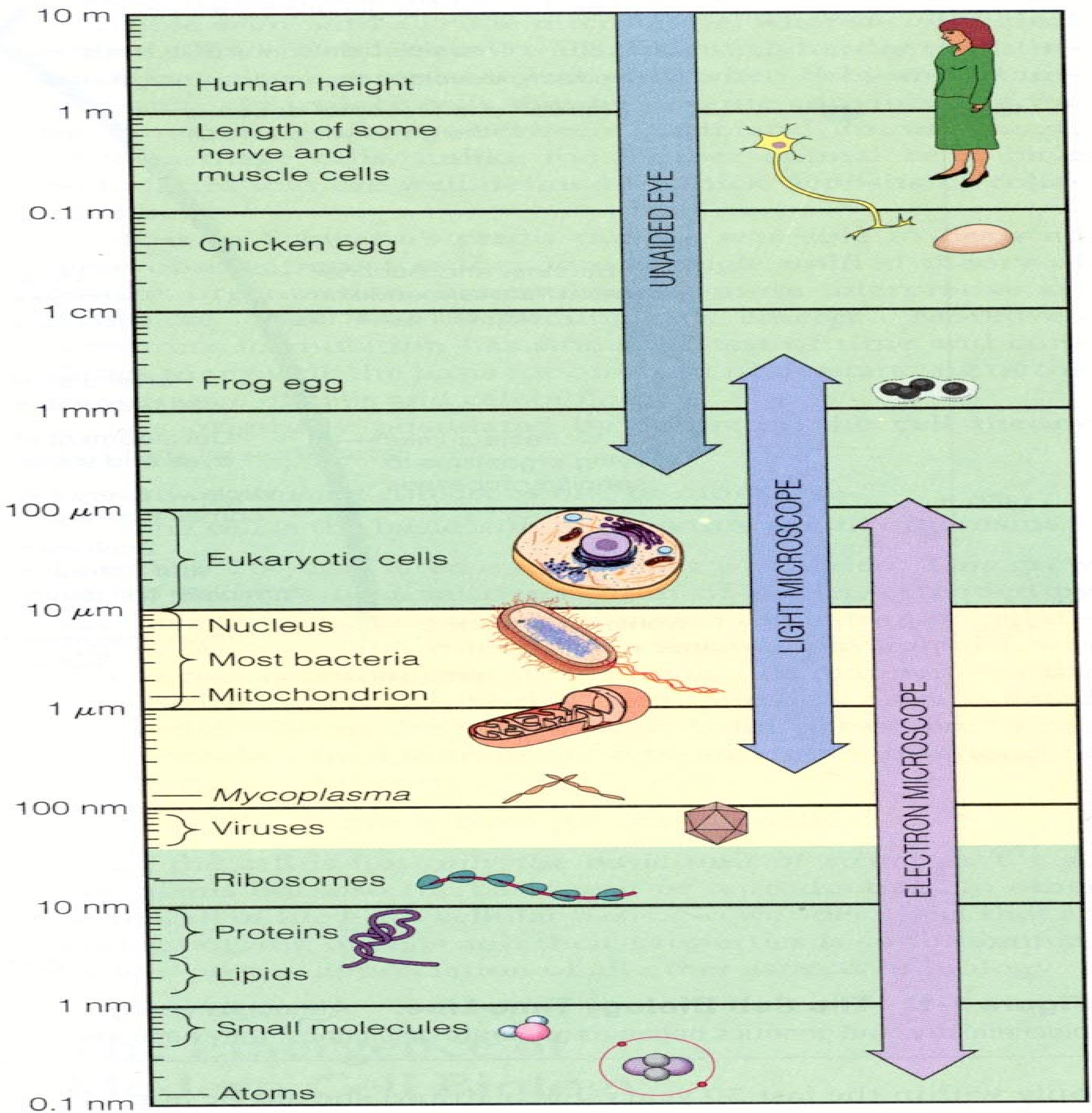
THE CELL

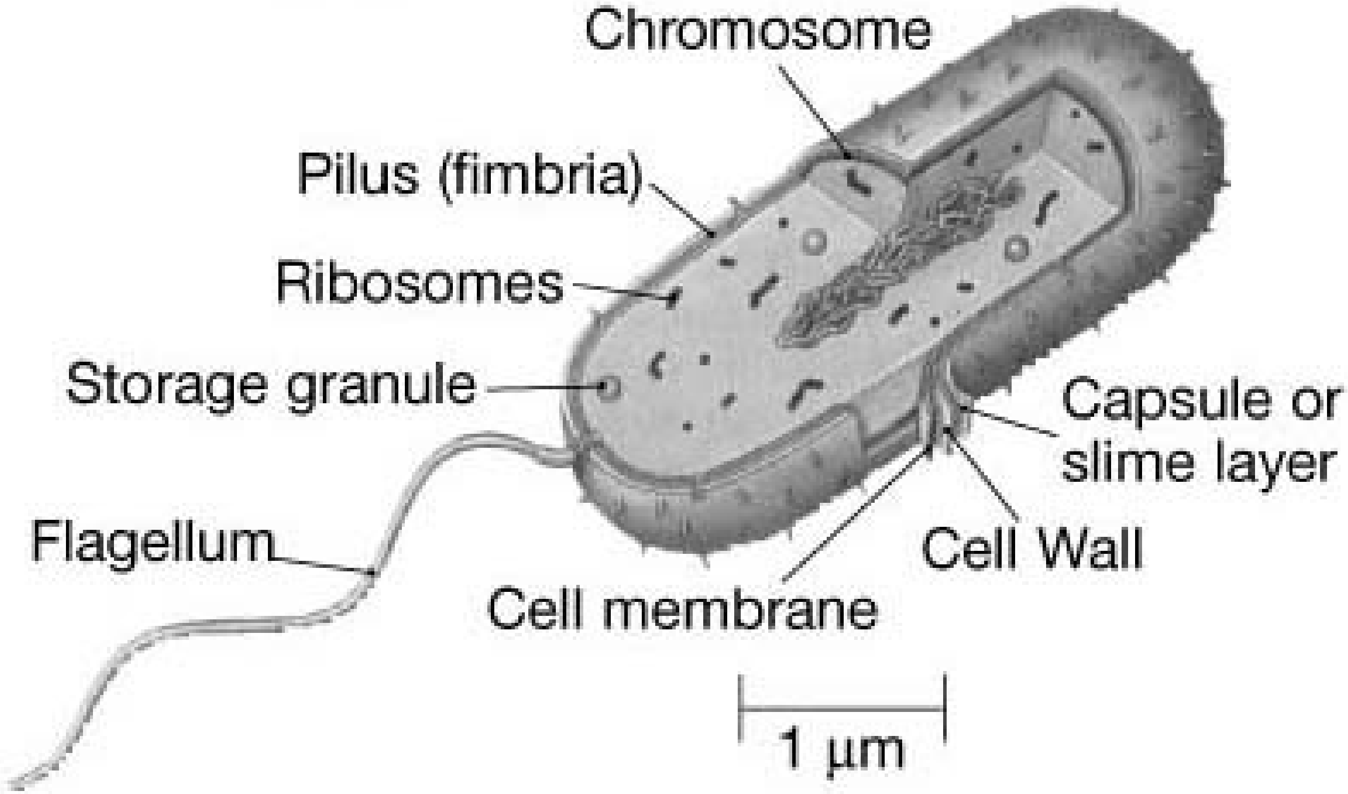
ITS STRUCTURE and FUNCTION

WHAT DO CELLS DO AND HOW DO THEY DO IT?

BASIC CELL COMPONENTS

- Plasma membrane - Lipid bilayer
- Cytoplasm - all cellular componets except the Nucleus
  - Cytosol - fluid portion
  - Organelles - subcellular structures
- Nucleus


10 m
Human height
1 m
Length of some nerve and muscle cells
0.1 m
Chicken egg
1 cm
Frog egg
1 mm
100 µm
Eukaryotic cells
10 µm
Nucleus
Most bacteria
Mitochondrion
1 µm
Mycoplasma
100 nm
Viruses
Ribosomes
10 nm
Proteins
Lipids
1 nm
Small molecules
Atoms
0.1 nm
UNAIDED EYE
LIGHT MICROSCOPE
ELECTRON MICROSCOPE



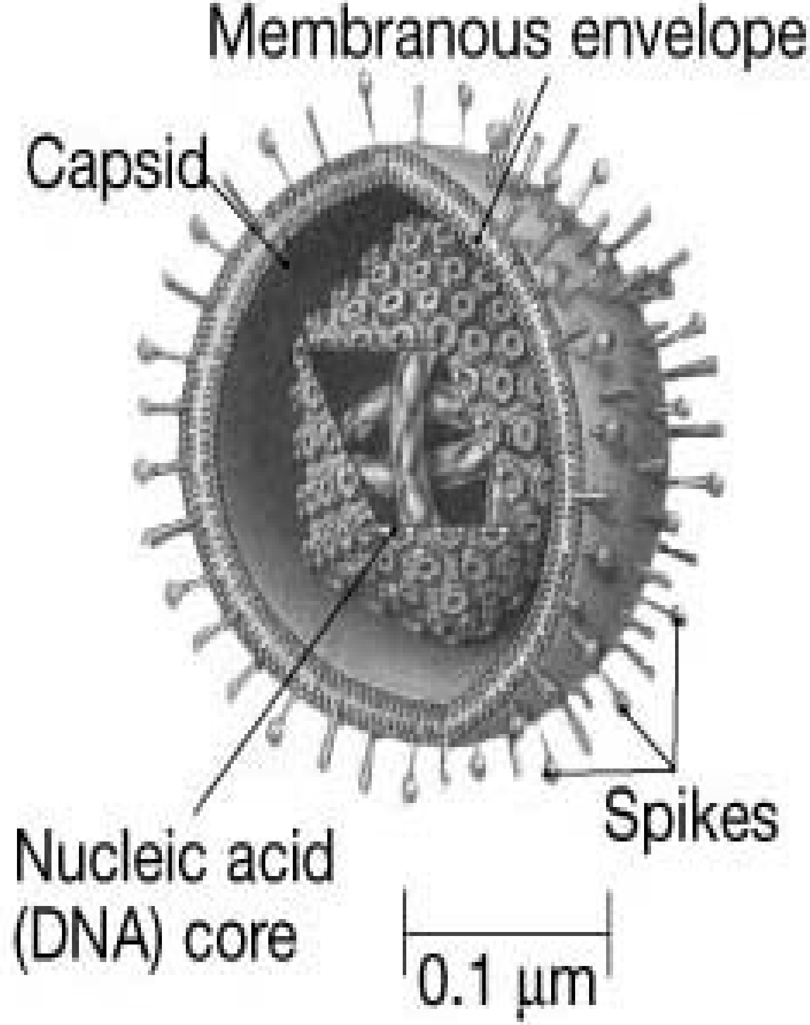
(a) Bacterium

Figure A-6 Representative Pathogens.

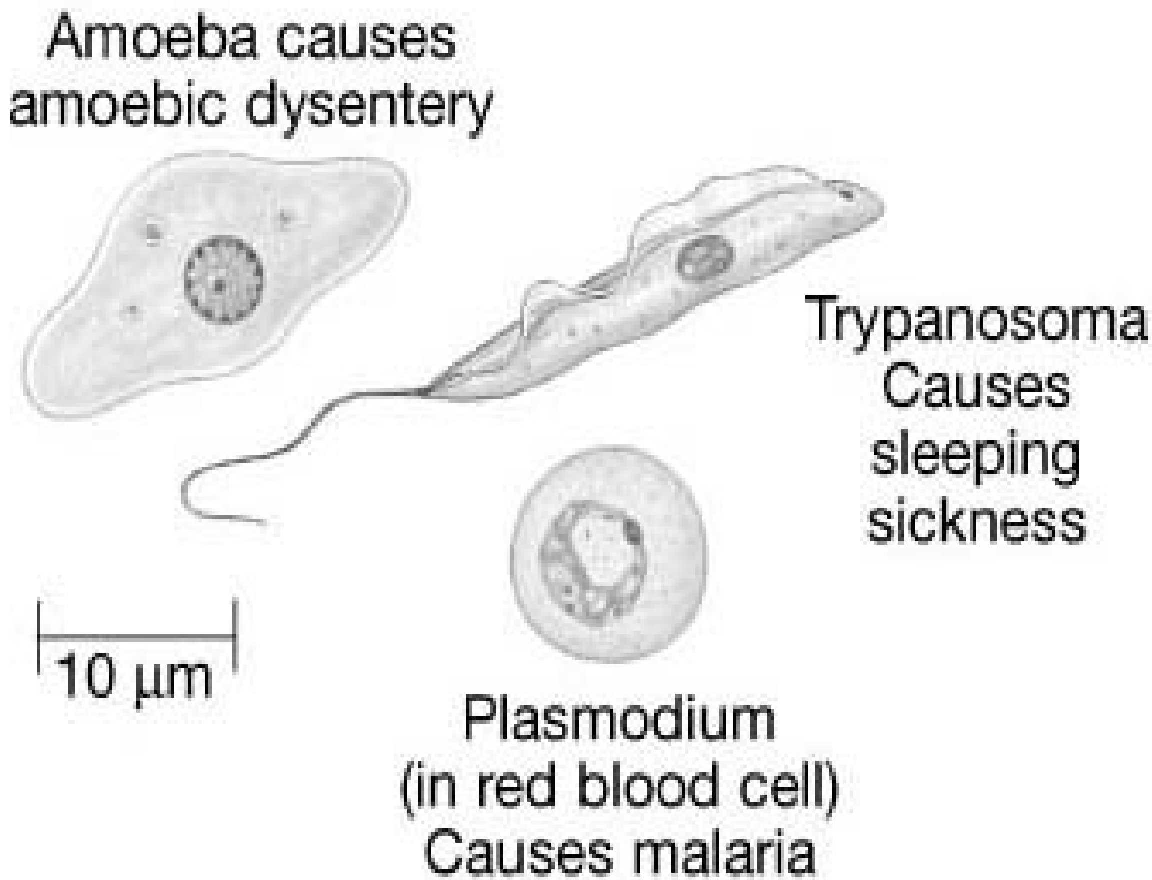
(a) A bacterium, with prokaryotic characteristics indicated.

Figure A-6 Representative Pathogens.

(b) A typical virus. Each virus has an inner chamber containing nucleic acid, surrounded by a protein capsid or an inner capsid and an outer membranous envelope. The herpes viruses are enveloped DNA viruses; they cause chickenpox, shingles, and herpes.



(b) Virus



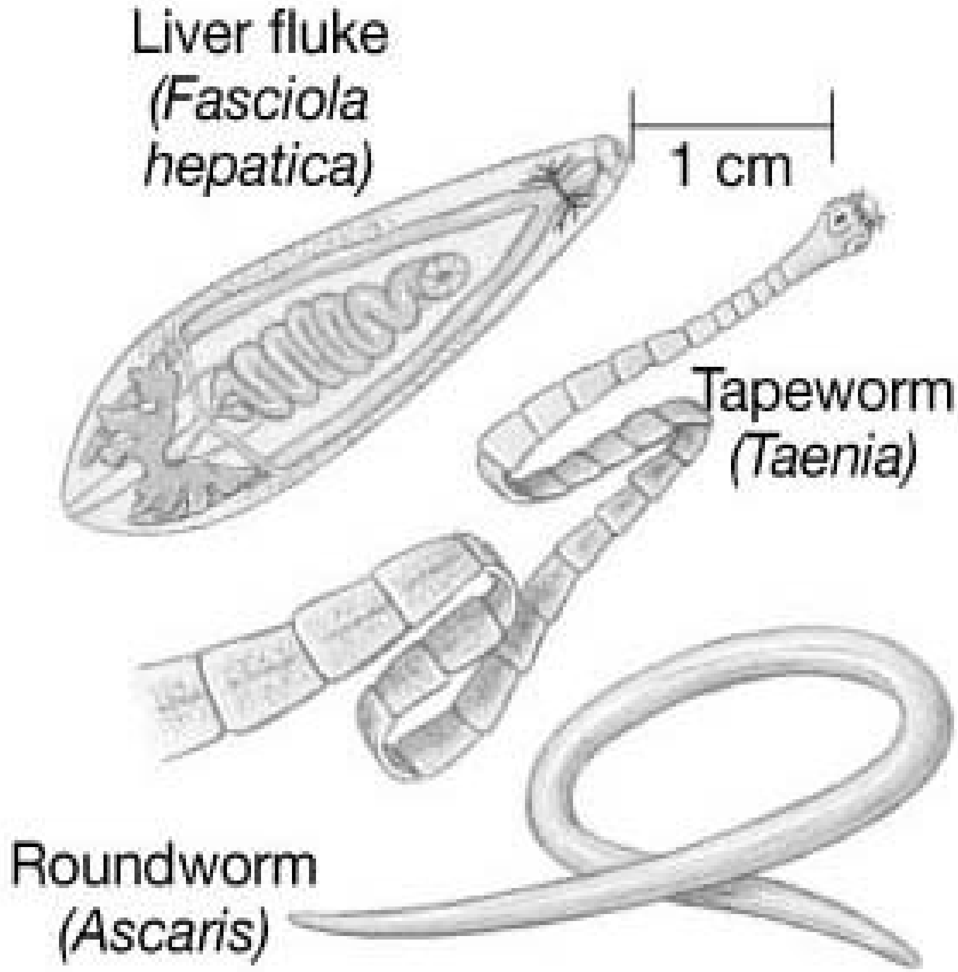
(c) Protozoan parasites

Figure A-6 Representative Pathogens.

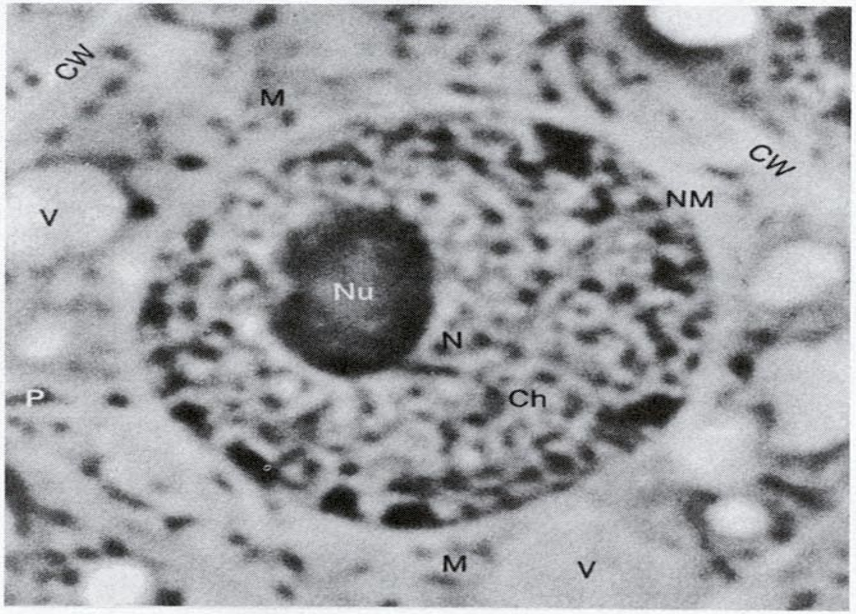
(c) Protozoan pathogens. Protozoa are eukaryotic, single-celled organisms, common in soil and water.

Figure A-6 Representative Pathogens.

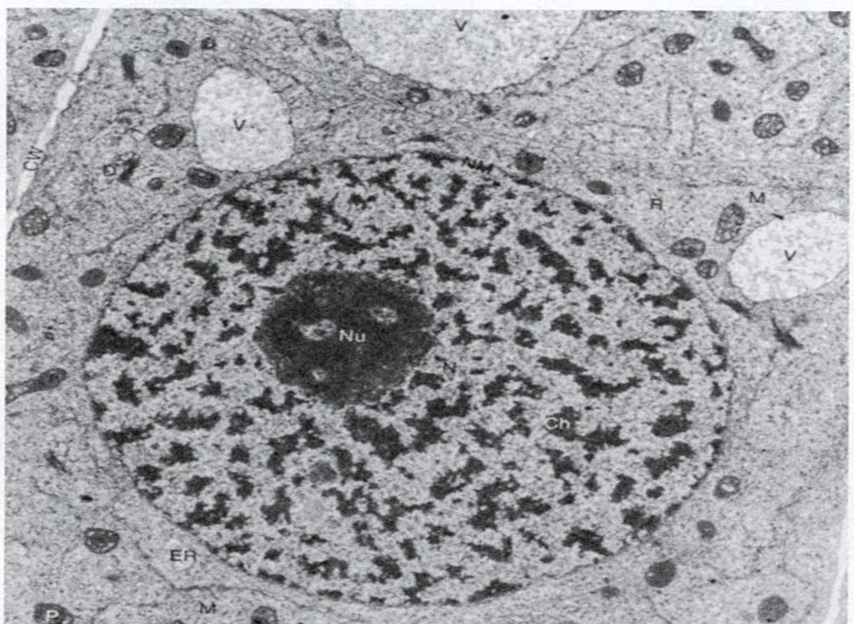
(d) Multicellular parasites. Several different groups of organisms are human parasites and many have complex life histories. Note: These illustrations are not drawn to a common scale.



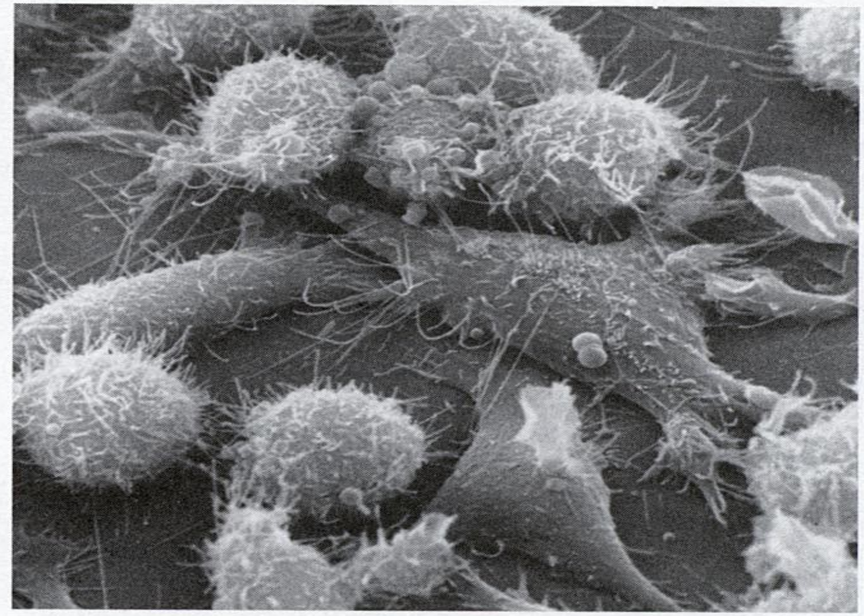
(d) Multicellular parasites



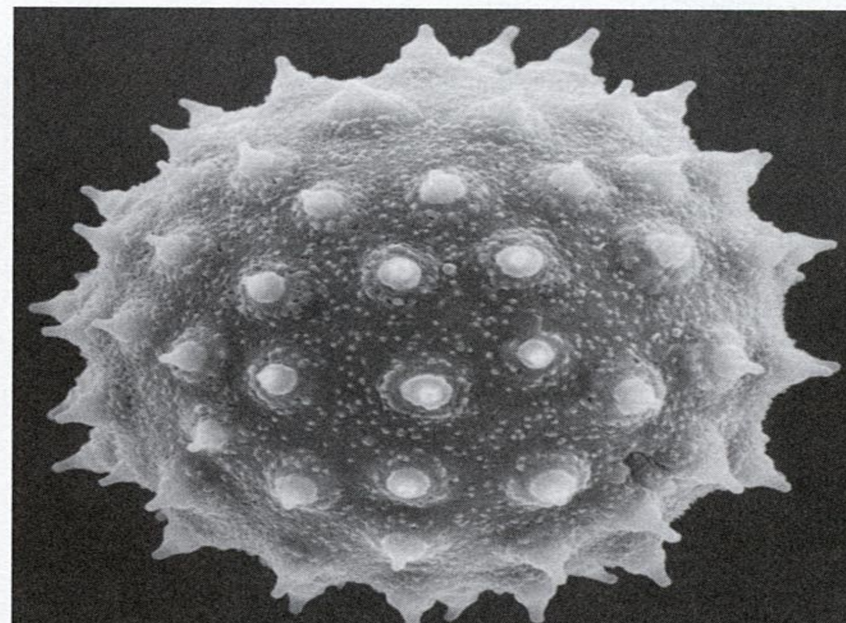
(a) Light microscopy — 50 μm



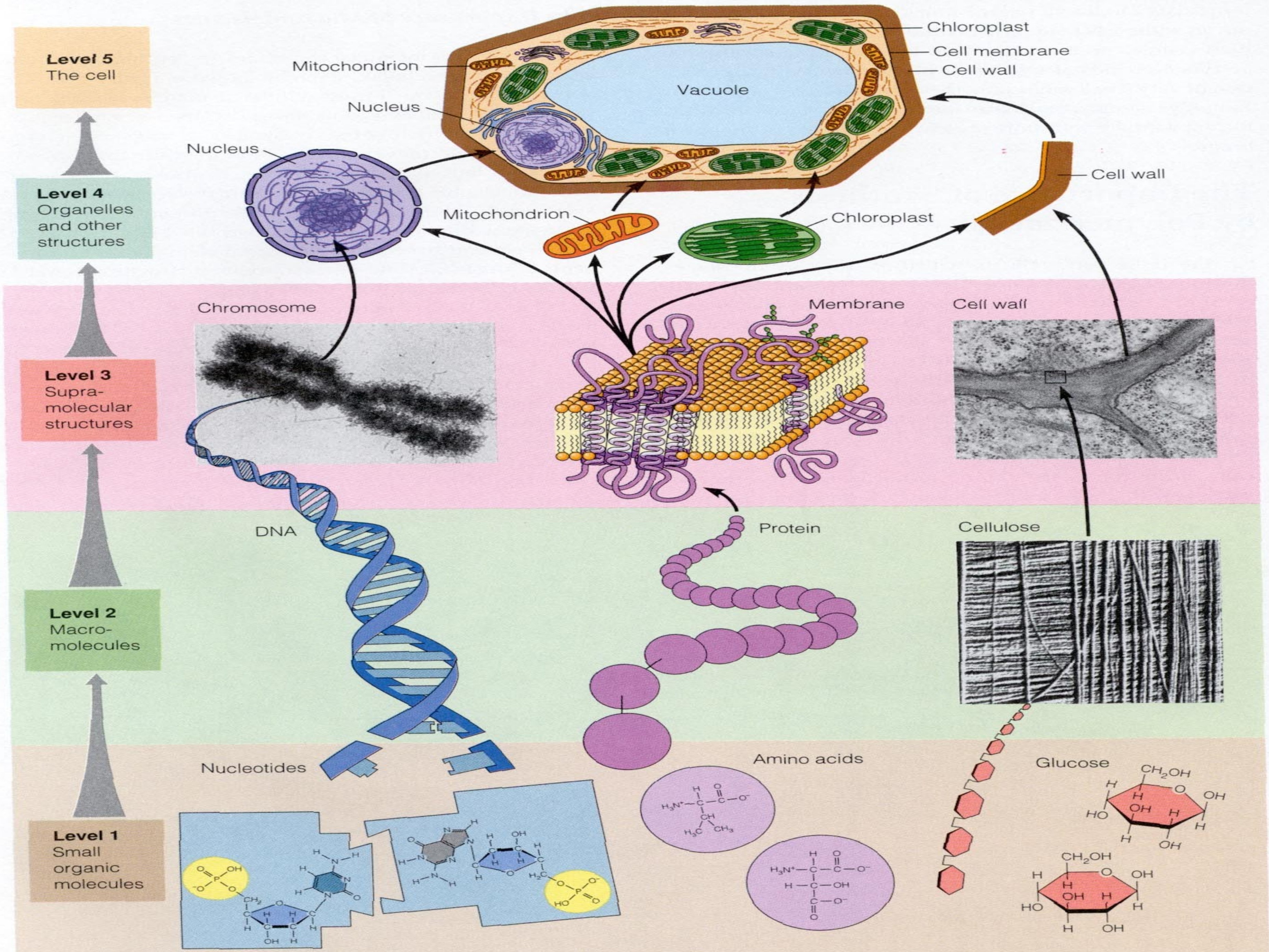
(b) Electron microscopy — 50 μm



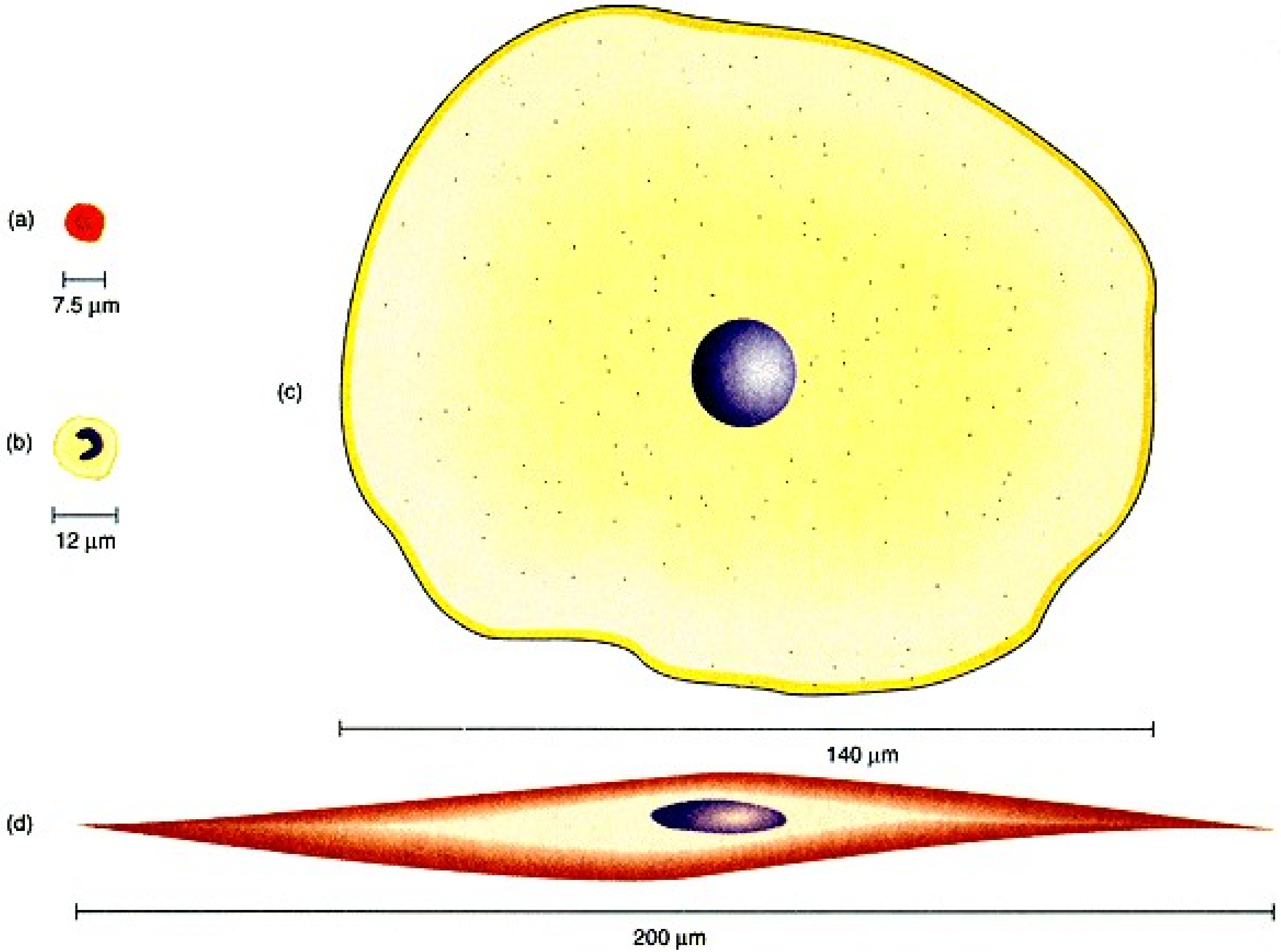
(a) Human neuroblastoma cells — 50 μm



(b) Pollen grain — 10 μm


Level 5
The cell
Level 4
Organelles and other structures
Level 3
Supra-molecular structures
Level 2
Macro-molecules
Level 1
Small organic molecules
Chloroplast
Cell membrane
Cell wall
Mitochondrion
Vacuole
Nucleus
Nucleus
Cell wall
Mitochondrion
Chloroplast
Chromosome
Membrane
Cell wall
DNA
Protein
Cellulose
Nucleotides
Amino acids
Glucose

Four Types of Cells.



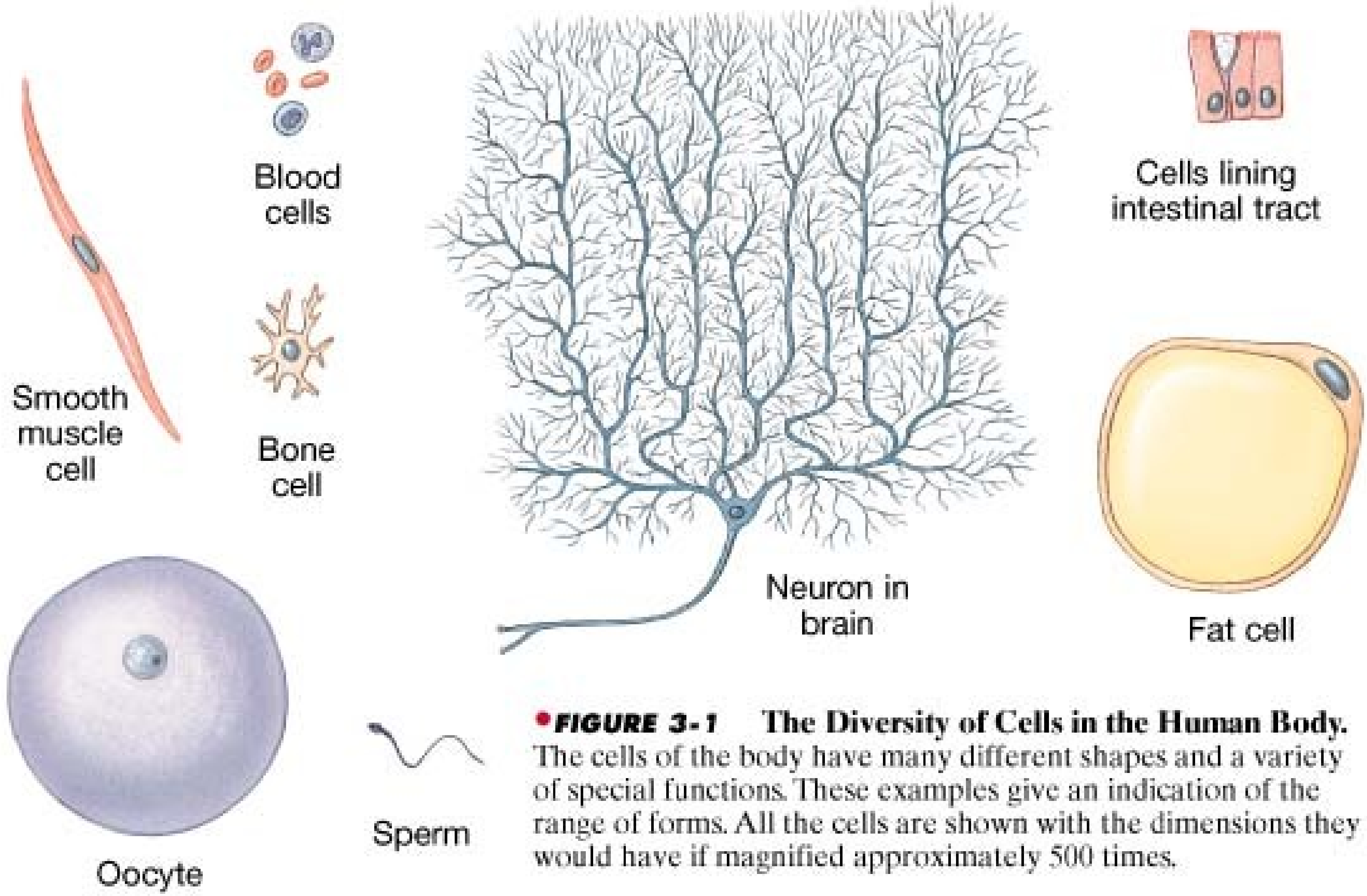
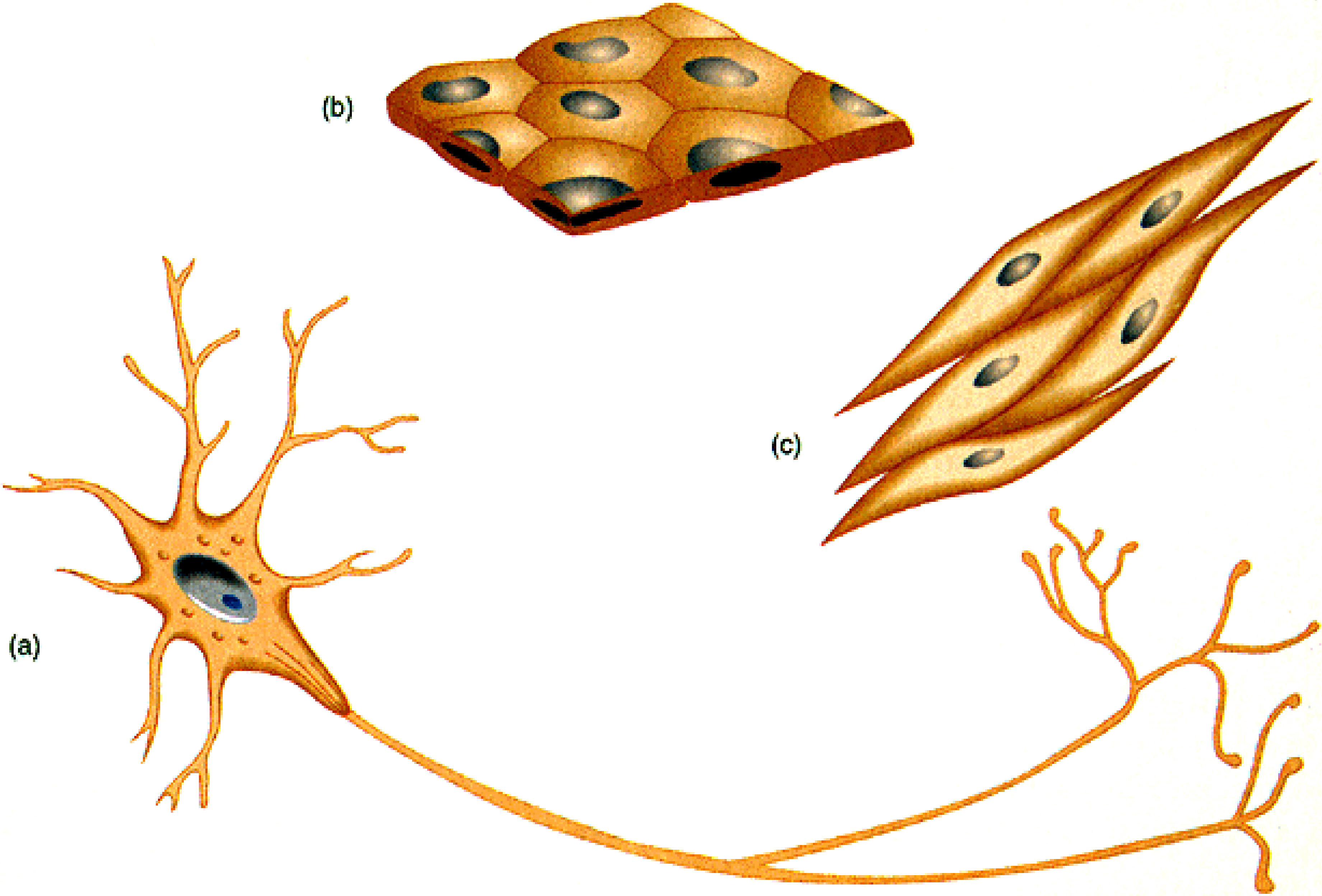
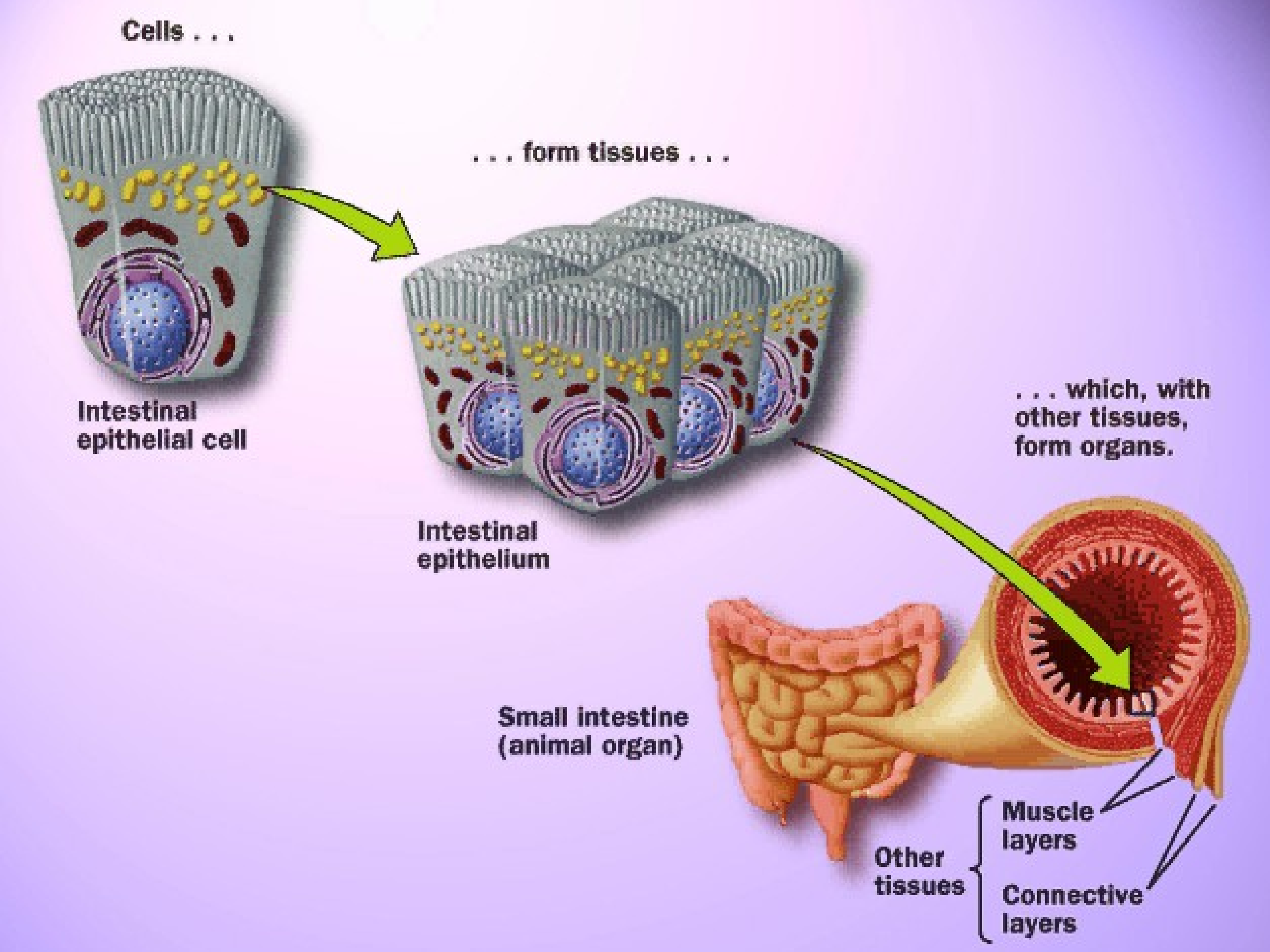


FIGURE 3-1 **The Diversity of Cells in the Human Body.** The cells of the body have many different shapes and a variety of special functions. These examples give an indication of the range of forms. All the cells are shown with the dimensions they would have if magnified approximately 500 times.

Cells Vary in Shape and Functions.

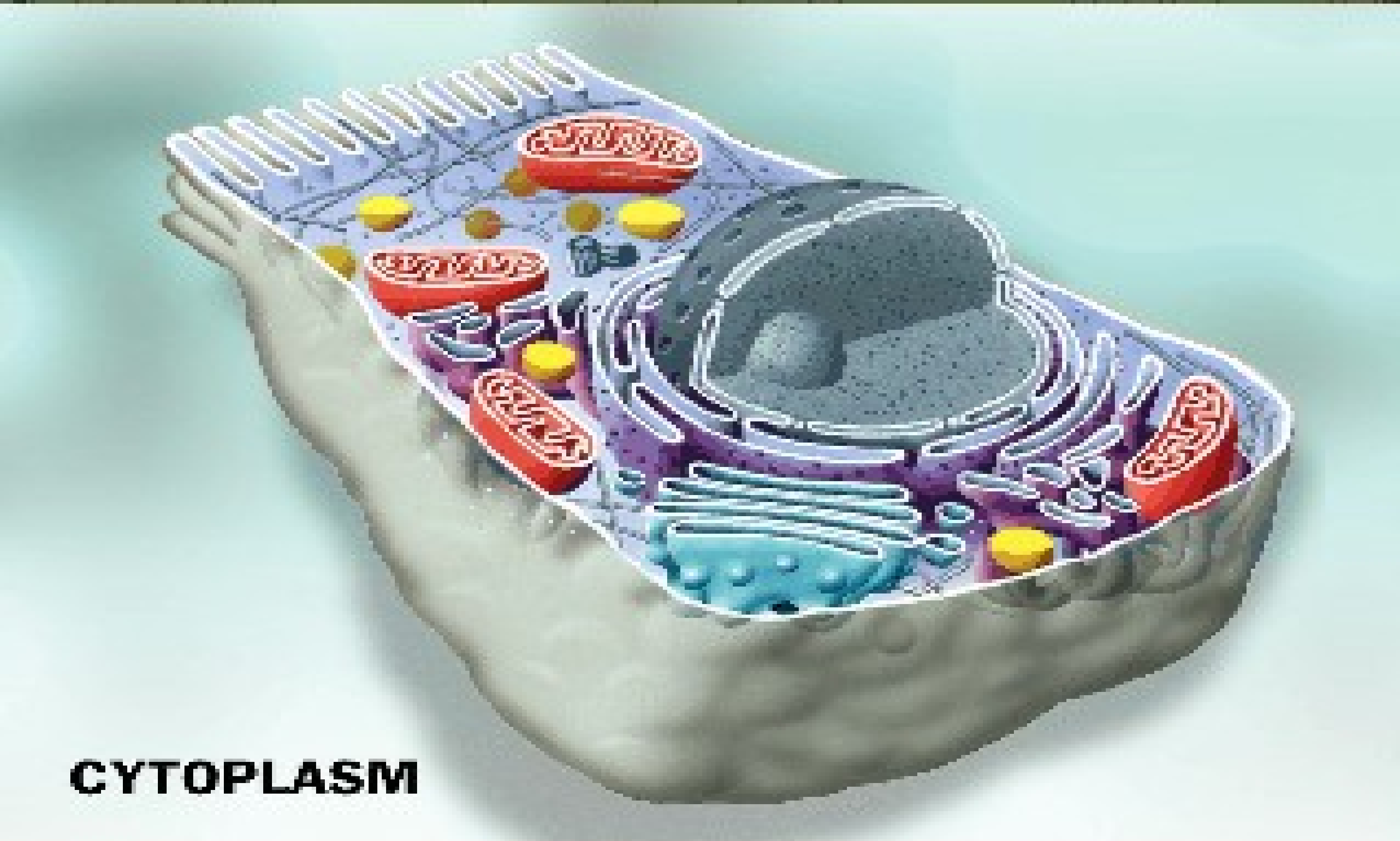




Cells . . .
Intestinal epithelial cell
. . . form tissues . . .
Intestinal epithelium
. . . which, with other tissues, form organs.
Small intestine (animal organ)
Other tissues
Muscle layers
Connective layers

The Cell

- The cell can be divided into three principal parts for ease of study:
- Plasma (cell) membrane
- Cytoplasm including
  - Cytosol
  - Organelles (except for the nucleus)
- Nucleus



Cytoplasm. Except for the nucleus, everything within the cell is cytoplasm.

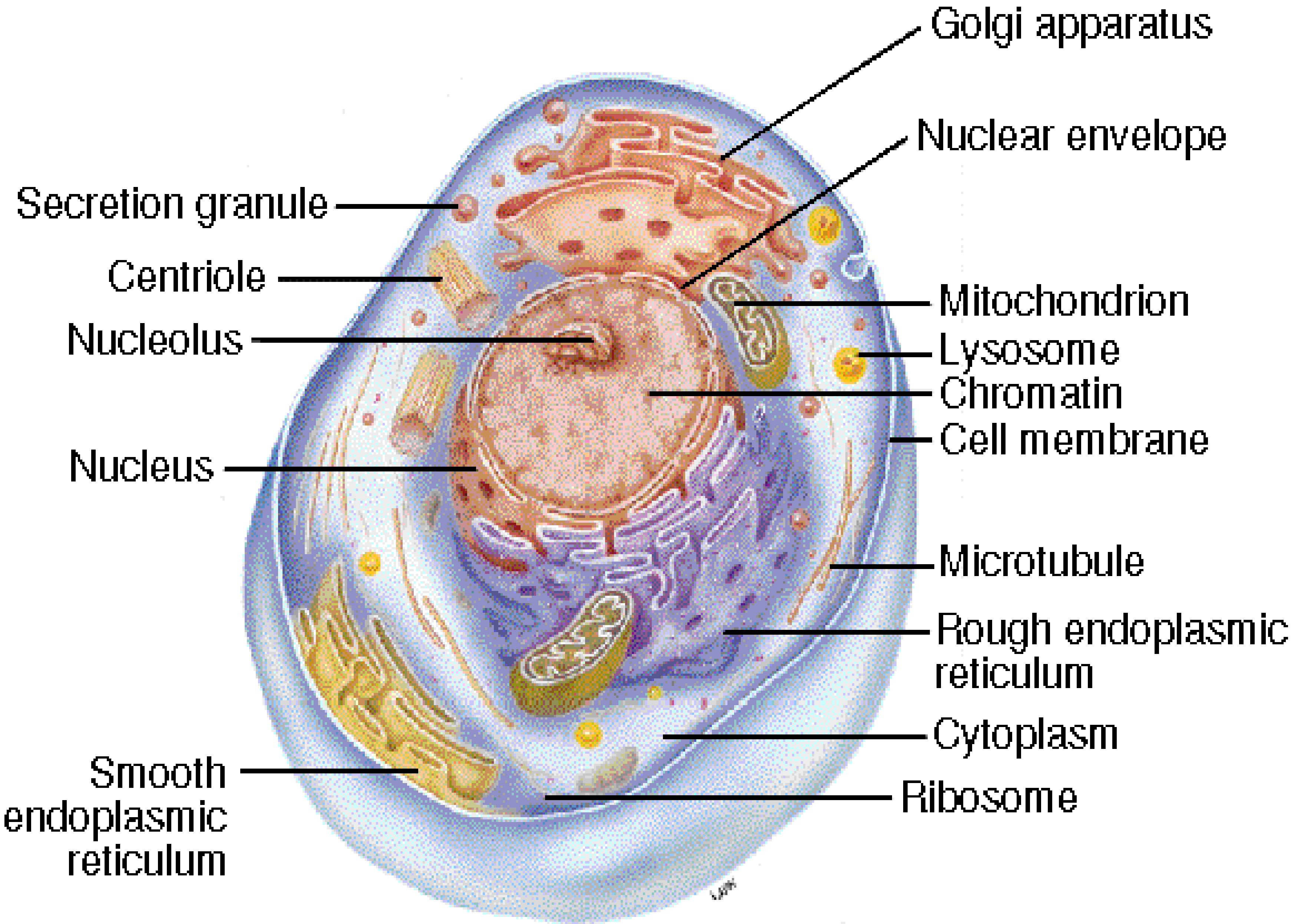
Cytoplasm

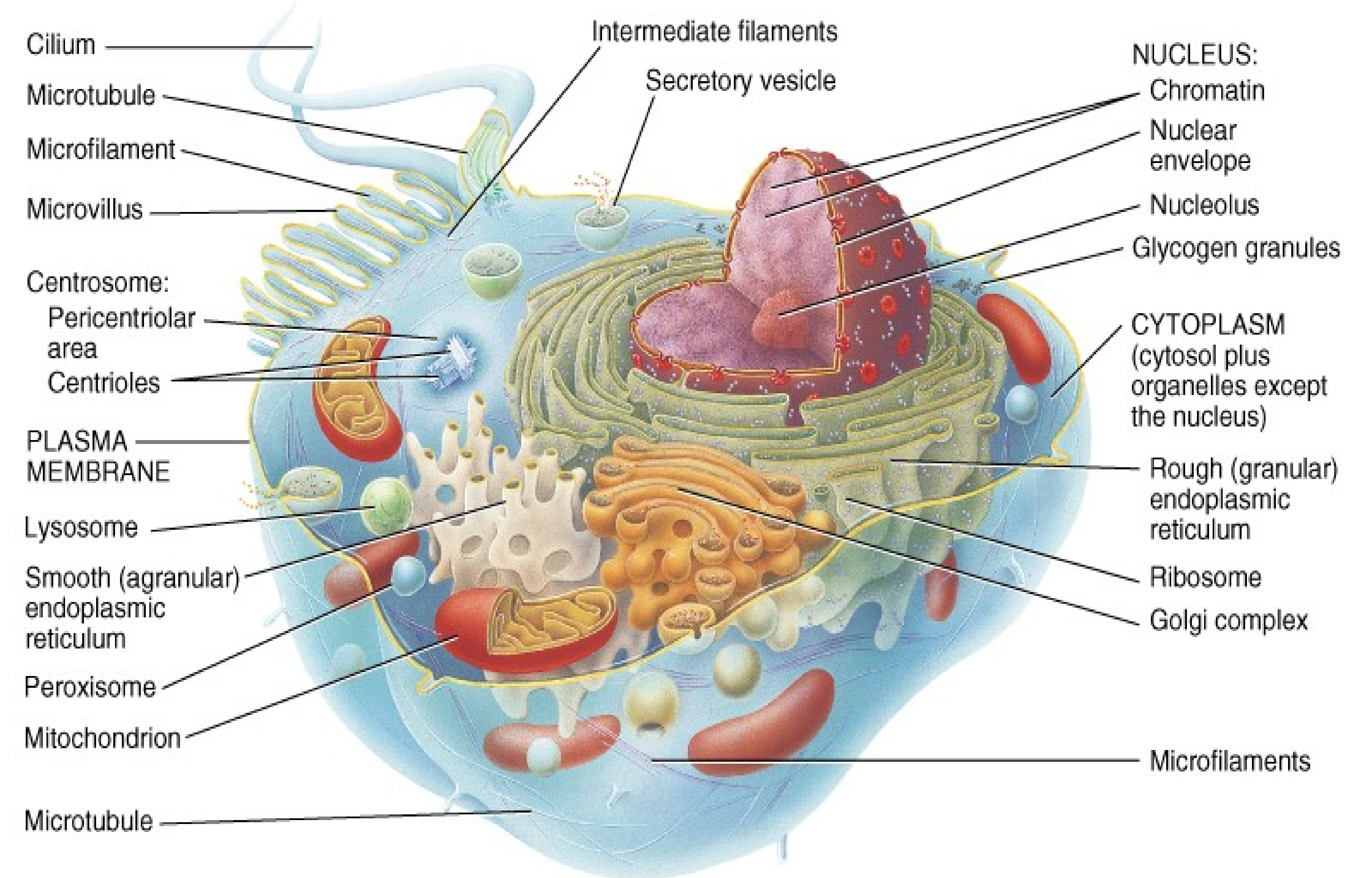
The cytoplasm is the contents of the cell, excluding the nucleus. The cytoplasm of eukaryotes includes many membrane-bounded organelles.

Cytosol

The liquid (non-particulate) part of the cytoplasm is called the cytosol. The organelles and cytoskeleton lie in the cytosol.

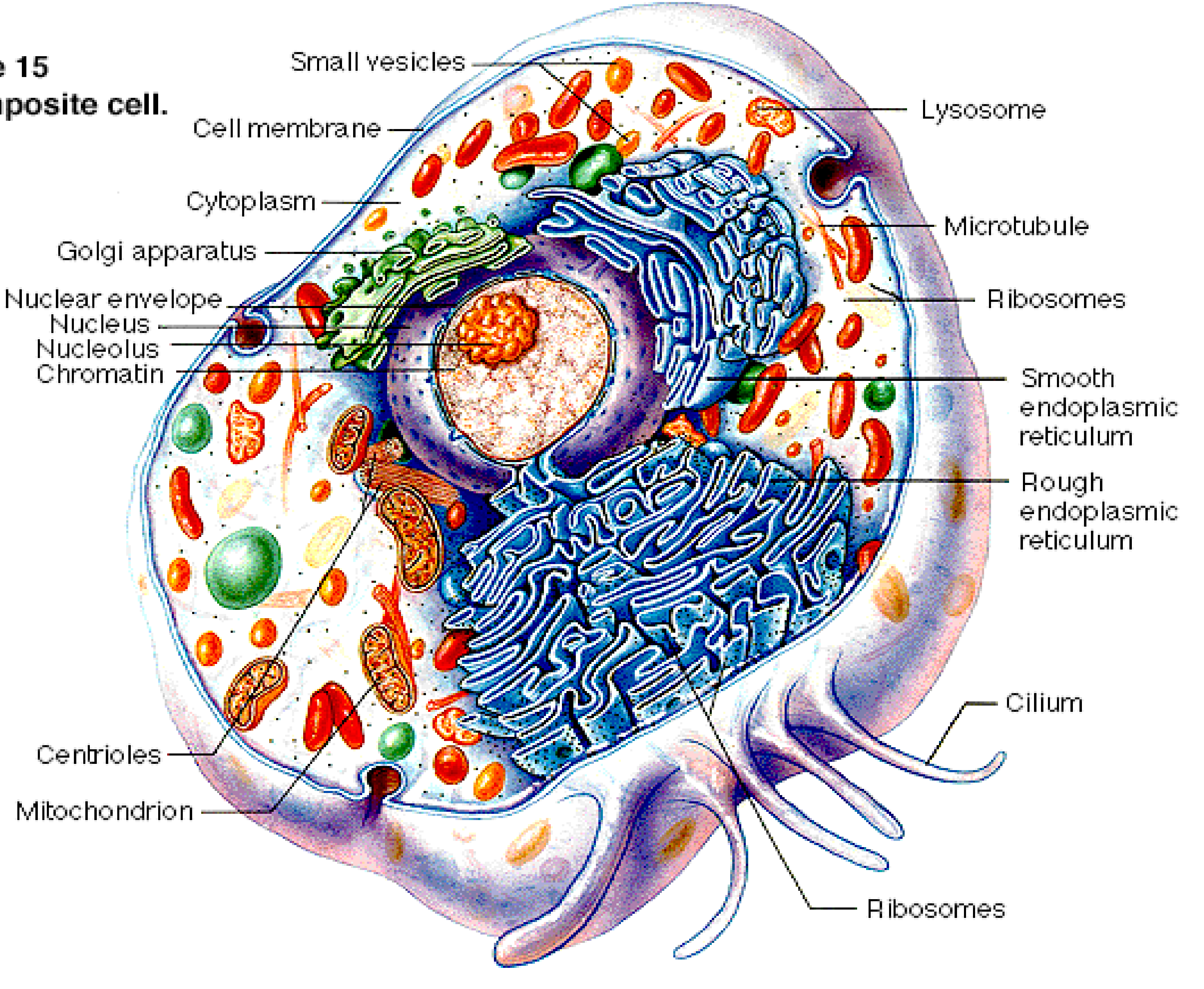
Generalized Cell.





Sectional view

Figure 15
A composite cell.



FLUID MOSAIC MODEL

- Describes the molecular arrangement of the plasma membrane = an ever-moving sea of lipids that contain a “mosaic” of many different proteins

The Plasma Membrane

- The plasma membrane is a flexible, sturdy barrier that surrounds and contains the cytoplasm of the cell.
  - The fluid mosaic model describes its structure (Fig. 3.2).
  - The membrane consists of proteins in a sea of lipids.

The Plasma Membrane

- The Lipid Bilayer
  - The lipid bilayer is the basic framework of the plasma membrane and is made up of three types of lipid molecules: phospholipids, cholesterol, and glycolipids.

Figure 14
Cell membrane framework.

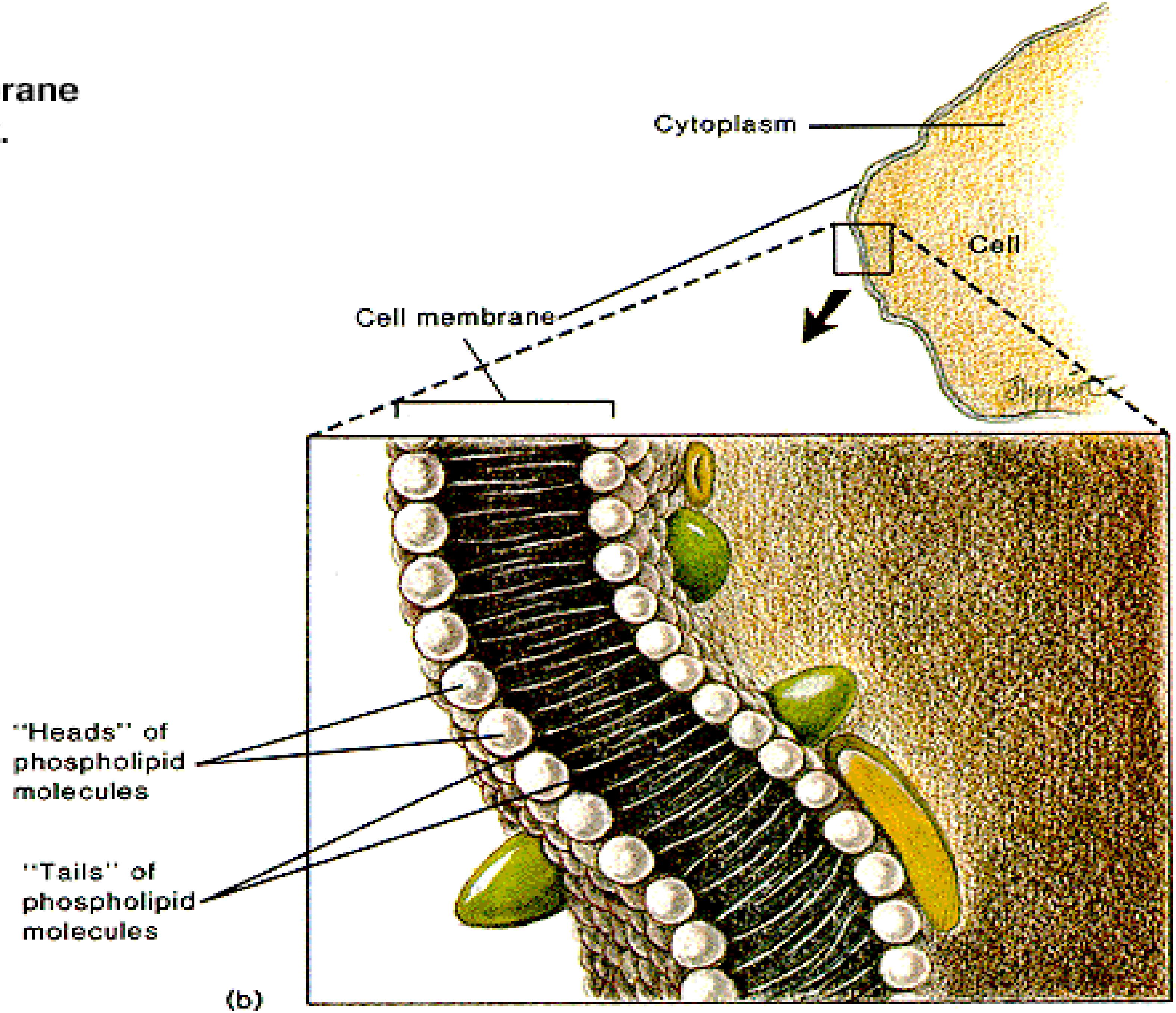
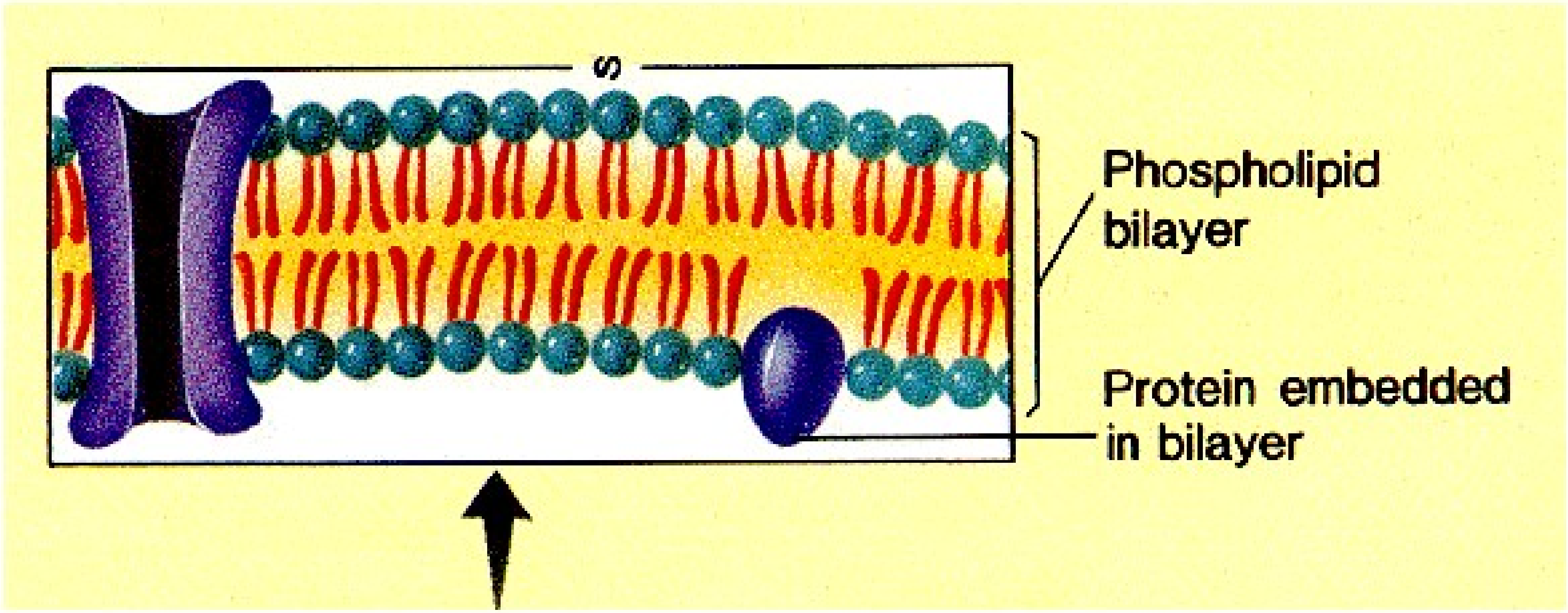
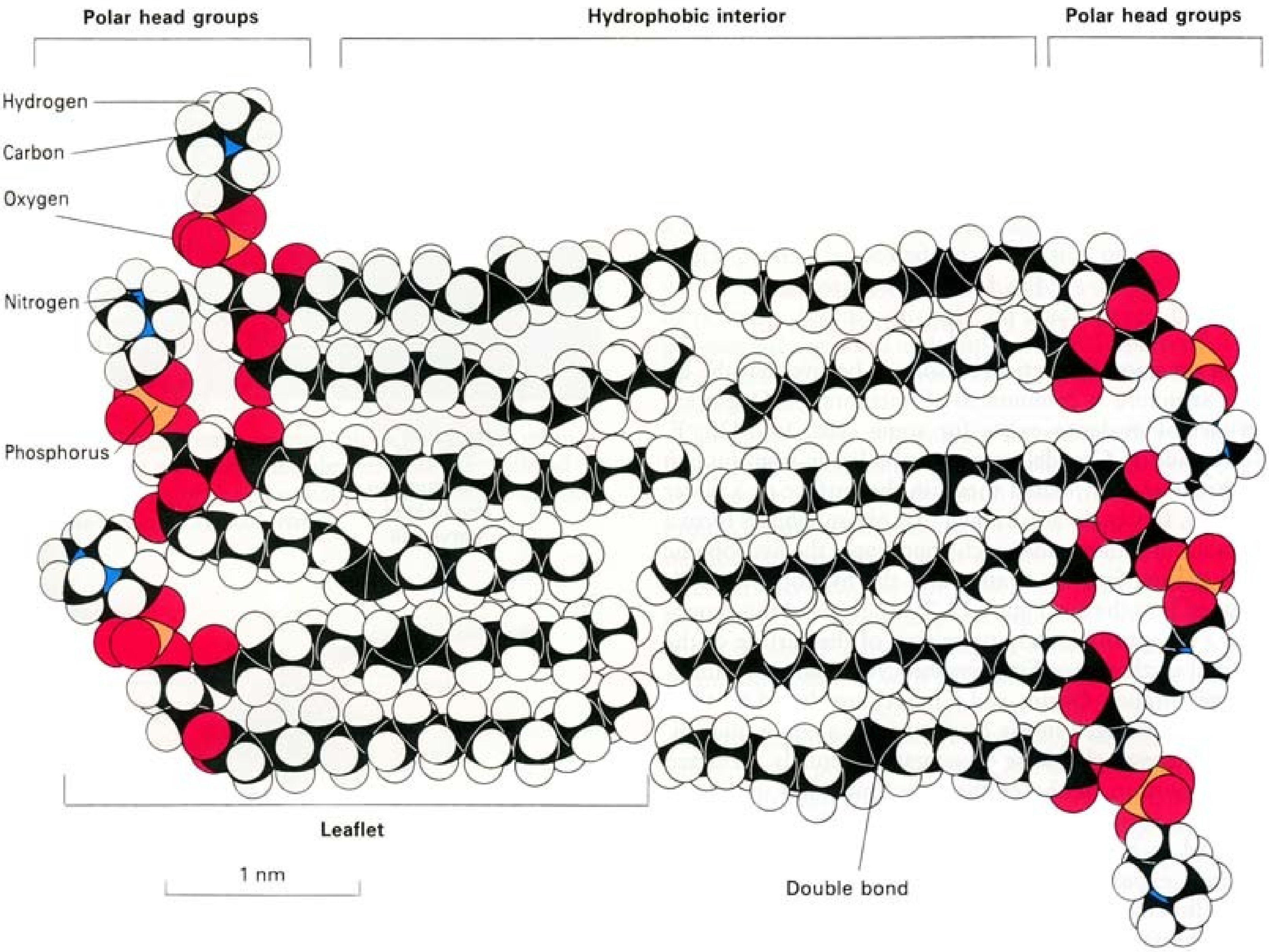
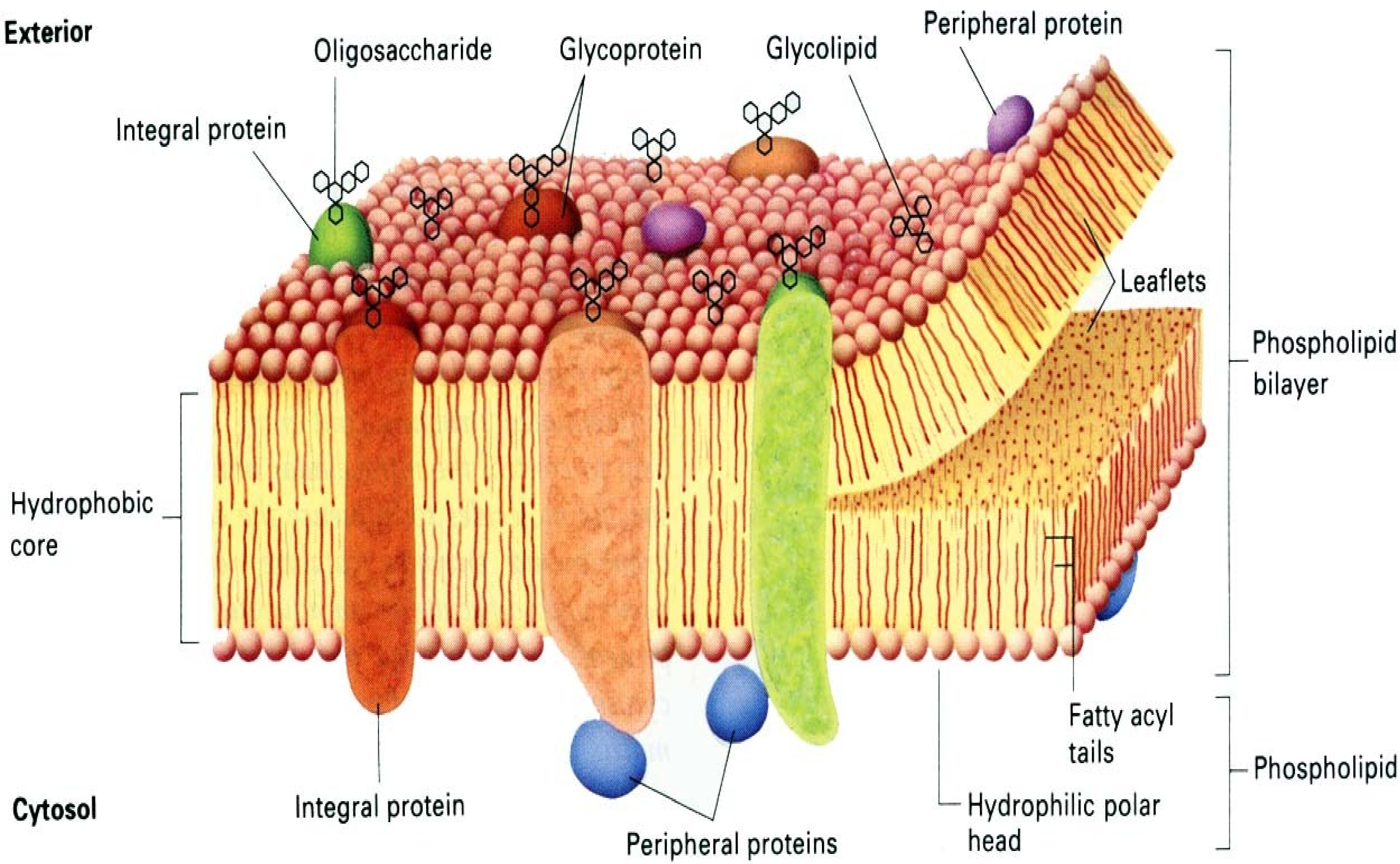


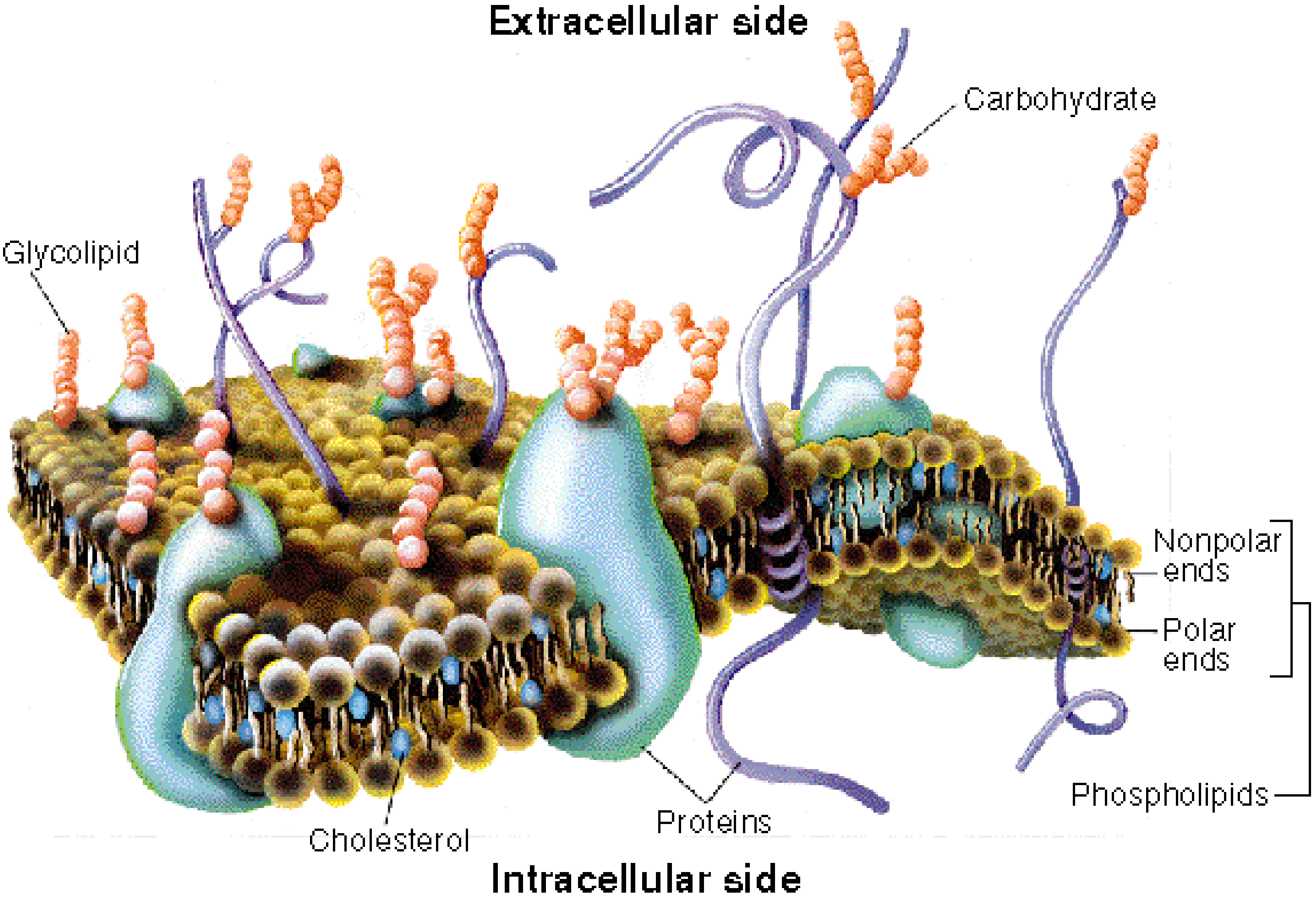
Figure 3
The plasma membrane.




Polar head groups
Hydrophobic interior
Polar head groups
Hydrogen
Carbon
Oxygen
Nitrogen
Phosphorus
Leaflet
1 nm
Double bond

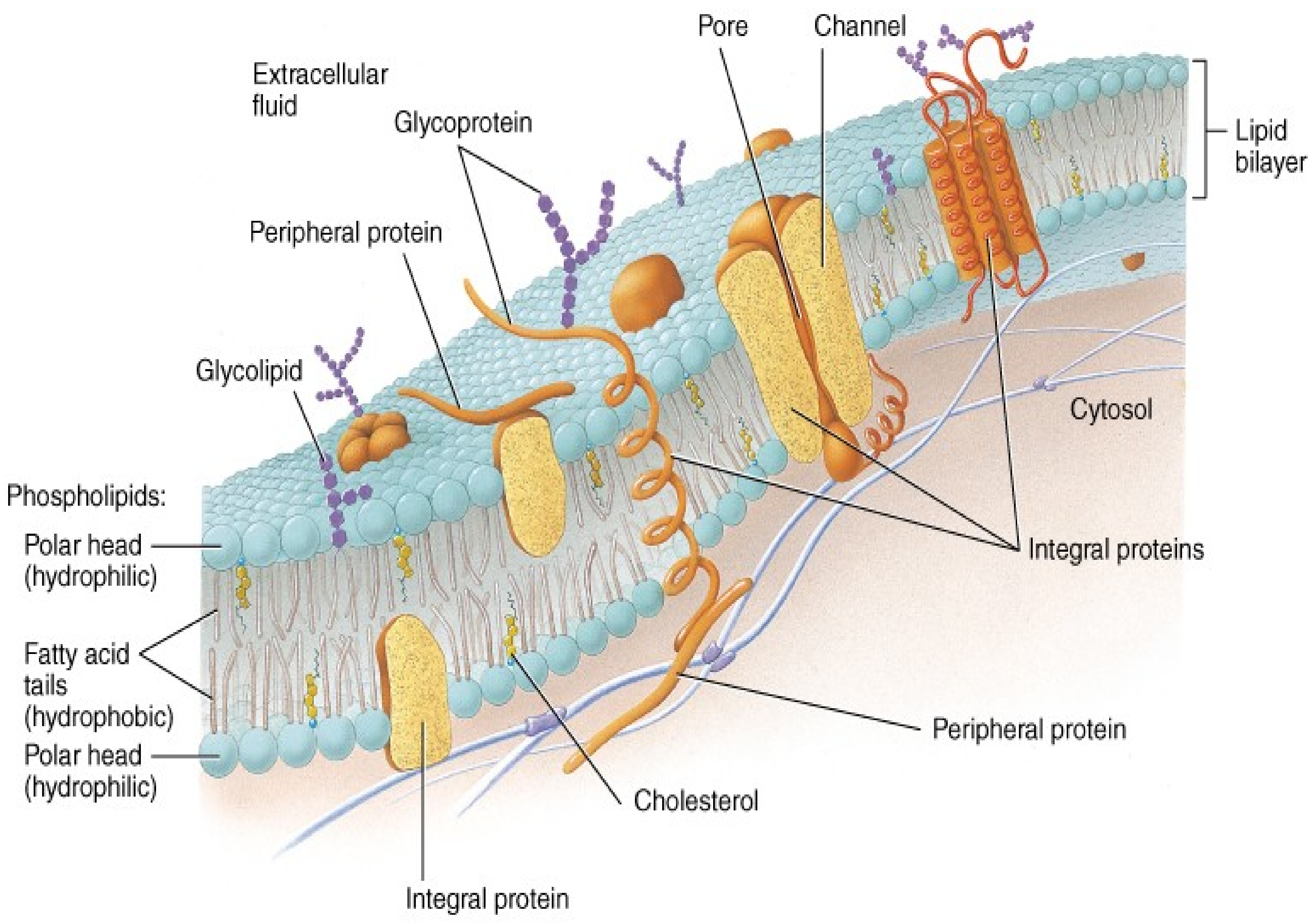

Exterior
Oligosaccharide
Glycoprotein
Glycolipid
Peripheral protein
Integral protein
Leaflets
Phospholipid bilayer
Hydrophobic core
Fatty acyl tails
Phospholipid
Cytosol
Integral protein
Peripheral proteins
Hydrophilic polar head

Fluid-Mosaic Model. Figure 3.2



PLASMA MEMBRANE

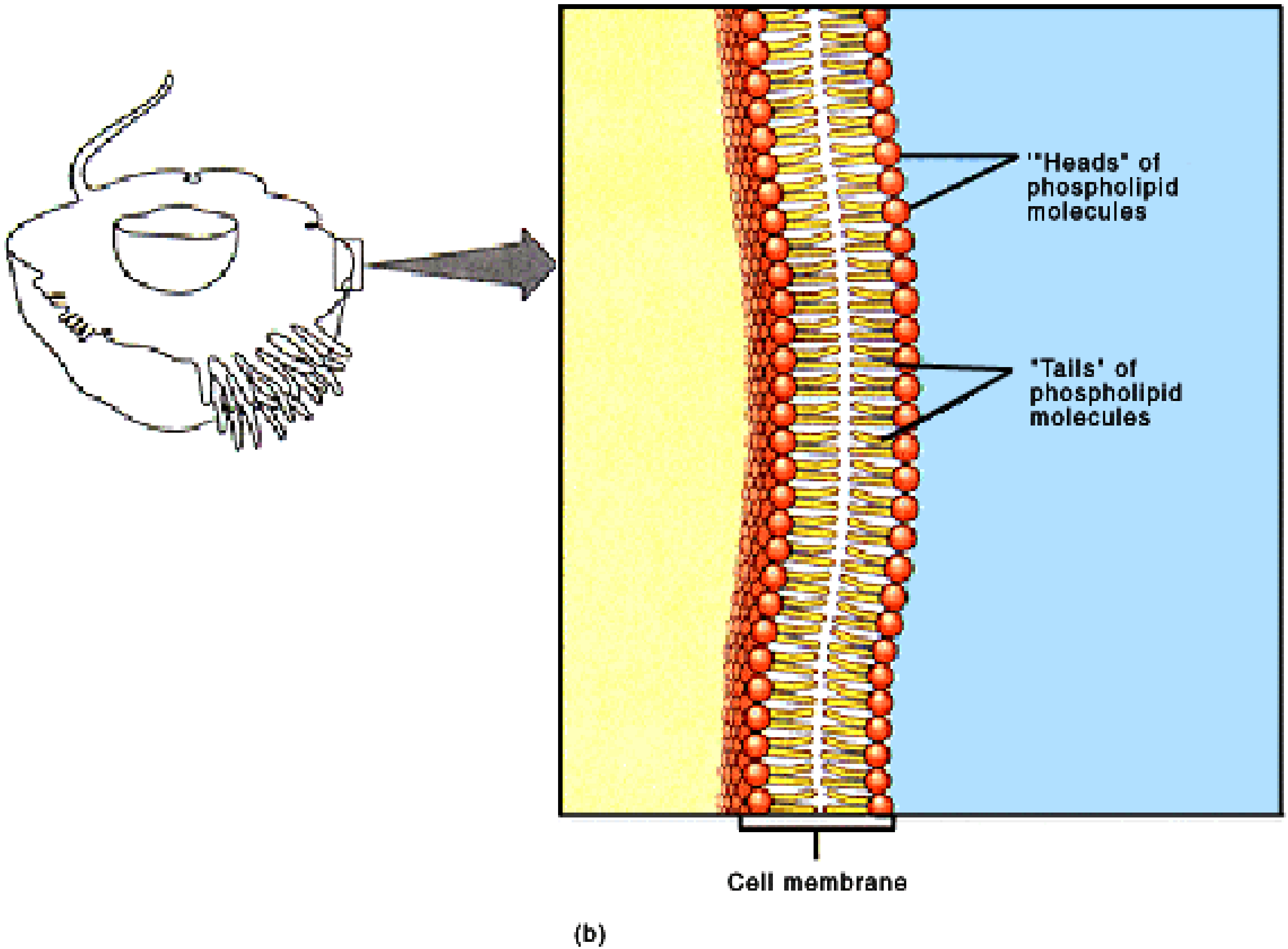
- Membrane proteins - largely reflect the functions of a cell:
  - Channel
  - Transporter
  - Receptor
  - Enzyme
  - Cell Identity Marker
  - Linker


Pore
Channel
Extracellular fluid
Glycoprotein
Lipid bilayer
Peripheral protein
Glycolipid
Cytosol
Phospholipids:
Polar head (hydrophilic)
Integral proteins
Fatty acid tails (hydrophobic)
Polar head (hydrophilic)
Peripheral protein
Cholesterol
Integral protein

The Plasma Membrane

- The bilayer arrangement occurs because the lipids are amphipathic molecules.
- They have both polar (charged) and nonpolar (uncharged) parts with the polar “head” of the phospholipid pointing out and the nonpolar “tail” pointing toward the center of the membrane.

Framework of the Membrane.



Arrangement of Membrane Proteins

- The membrane proteins are divided into integral and peripheral proteins.
  - Integral proteins extend into or across the entire lipid bilayer among the fatty acid tails of the phospholipid molecules.
  - Peripheral proteins are found at the inner or outer surface of the membrane and can be stripped away from the membrane without disturbing membrane integrity.

MEMBRANE PROTEINS

- **Integral membrane proteins** are amphipathic.
  - Those that stretch across the entire bilayer and project on both sides of the membrane are termed transmembrane proteins.
  - Many integral proteins are glycoproteins. The combined glycoproteins and glycolipids form the glycocalyx which helps cells recognize one another, adhere to one another, and be protected from digestion by enzymes in the extracellular fluid.

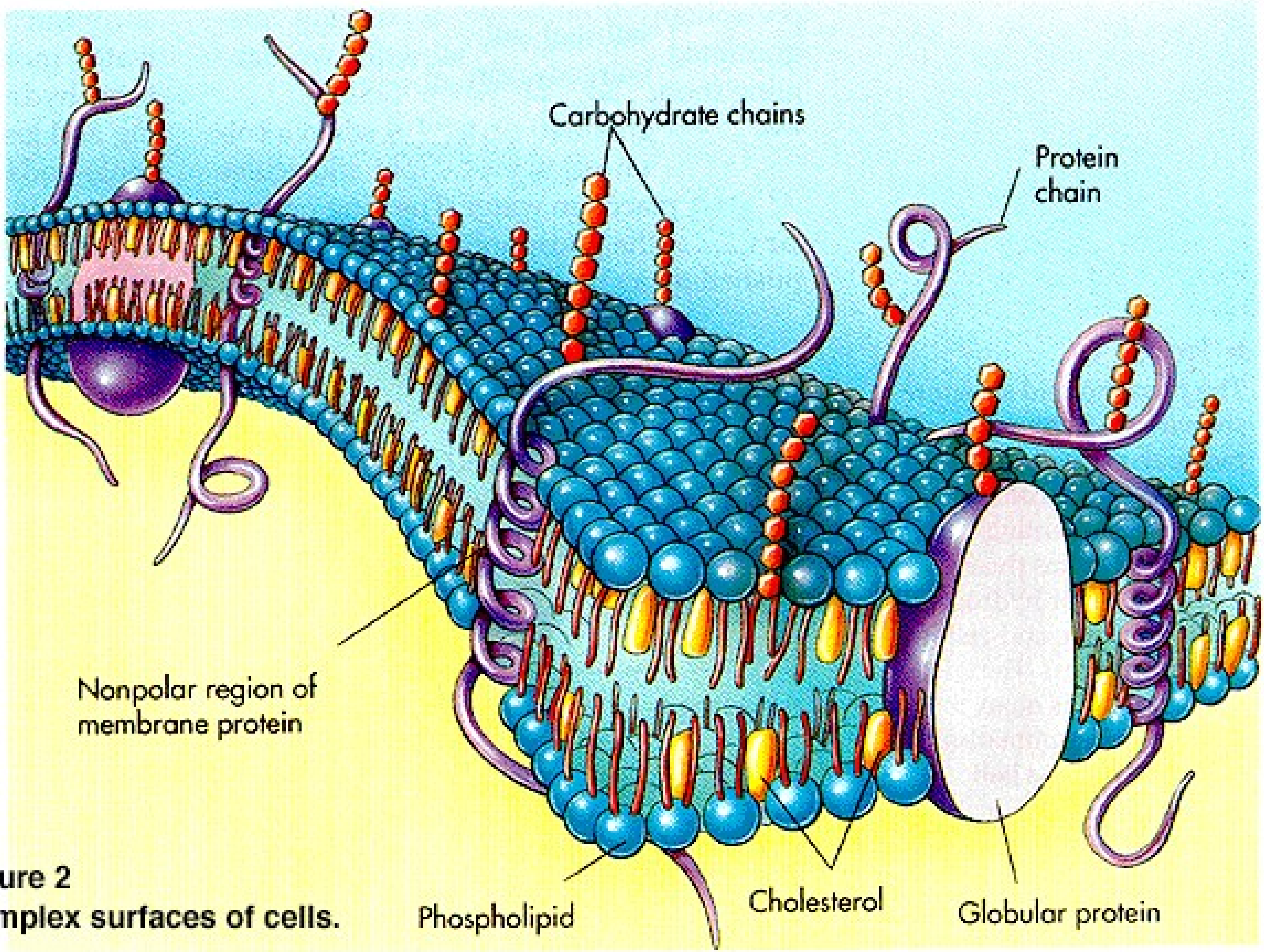


Figure 2
Complex surfaces of cells.

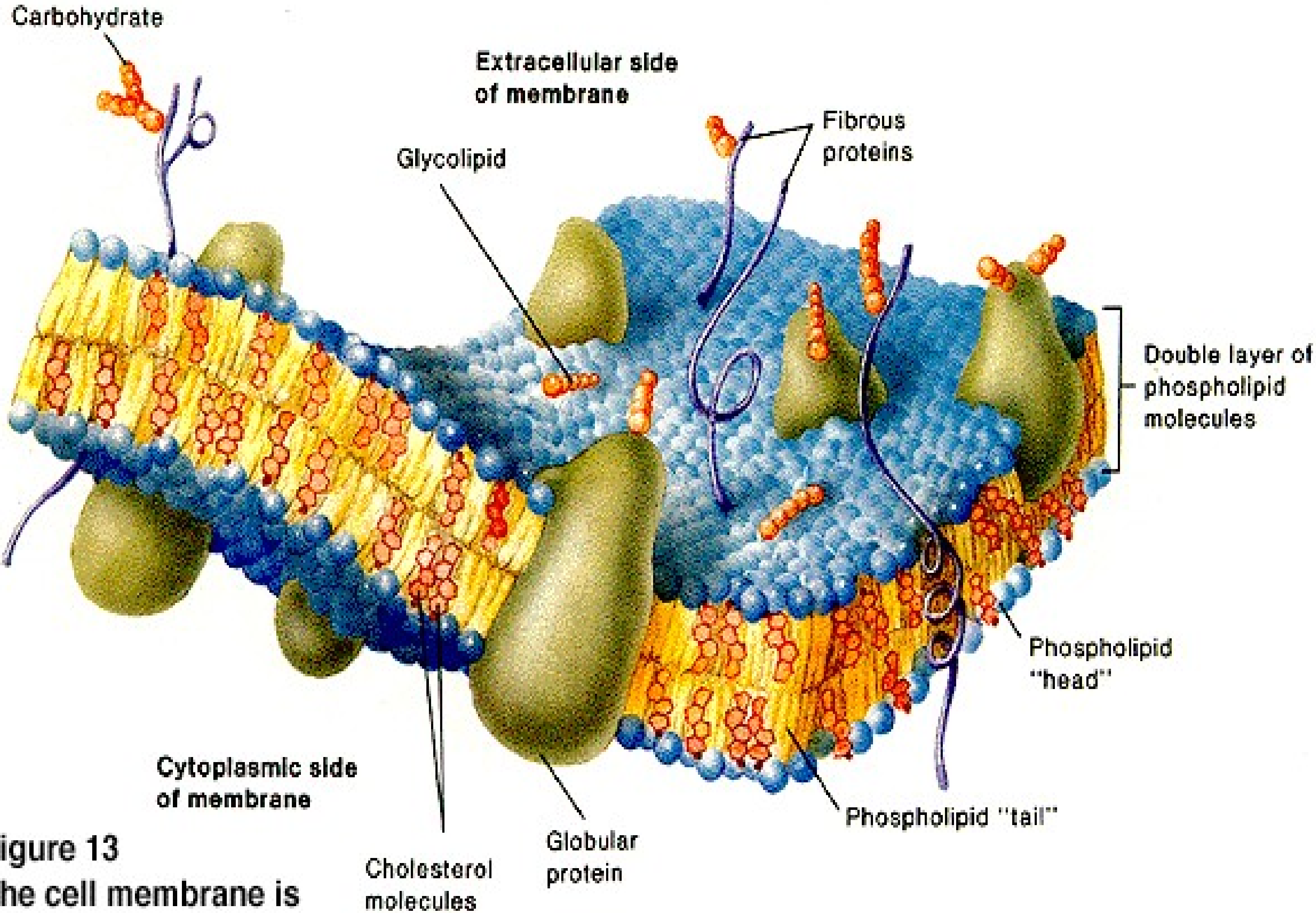
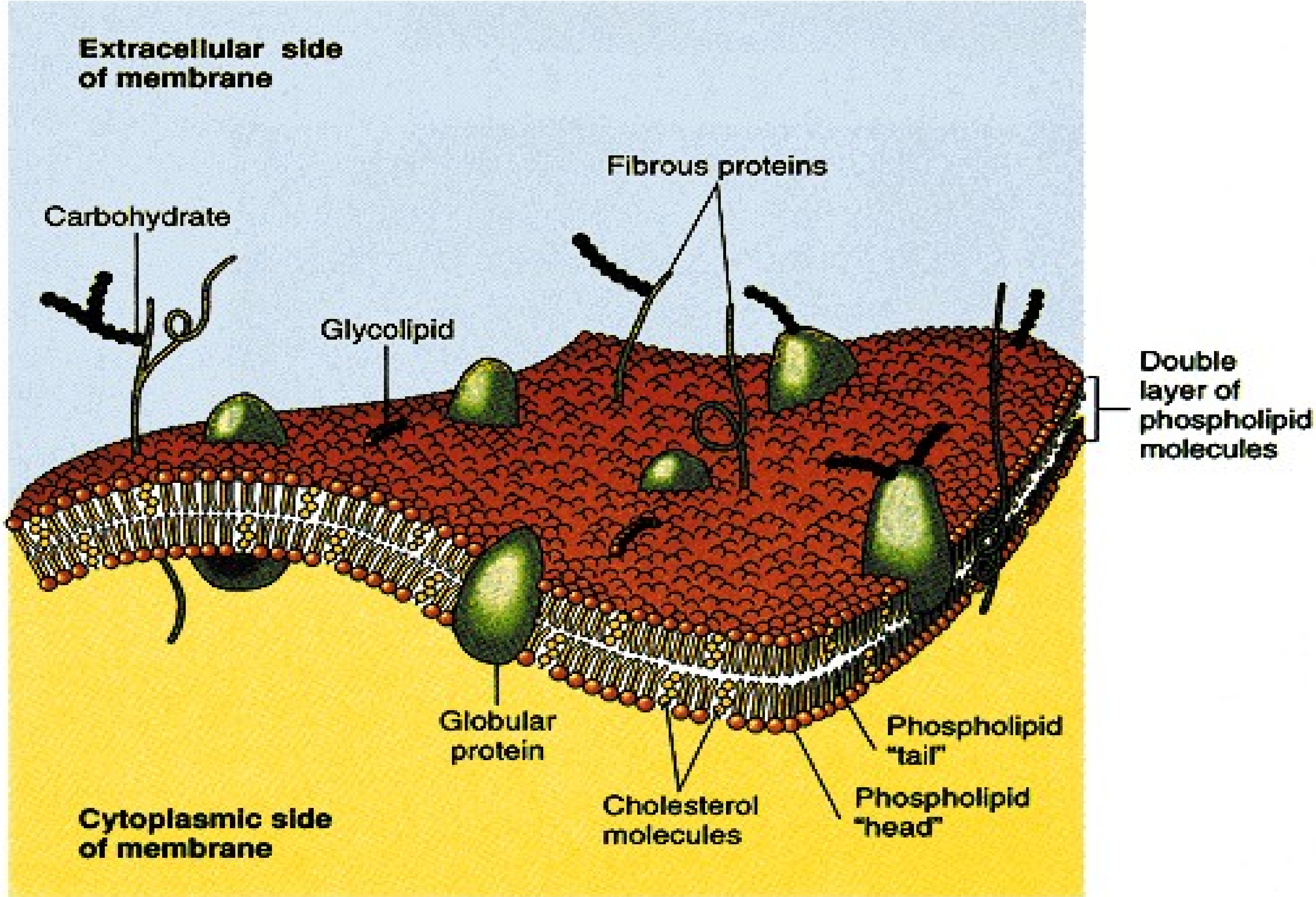


Figure 13
The cell membrane is composed primarily of phospholipids.

Cell Membrane.



Functions of Membrane Proteins

- Membrane proteins vary in different cells and functions as channels (pores), transporters, receptors, enzymes, cell-identity markers, and linkers (Fig. 3.3)
- The different proteins help to determine many of the functions of the plasma membrane.

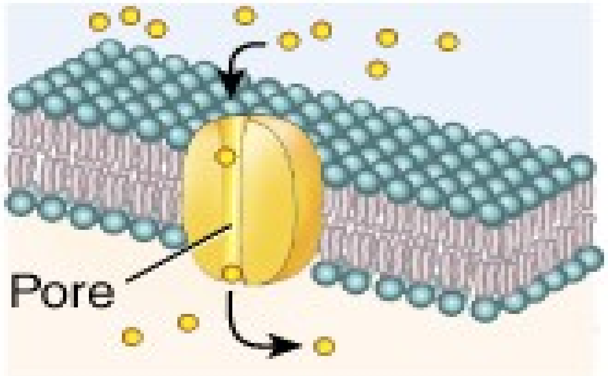
TYPICAL FUNCTIONS

- Anabolism/catabolism
  - Chapters 2, 4, 5, and some of 6
- Transport
  - Into and out of the cell
  - Intracellularly to cell processes
  - Extracellularly in hollow organs
- Divide

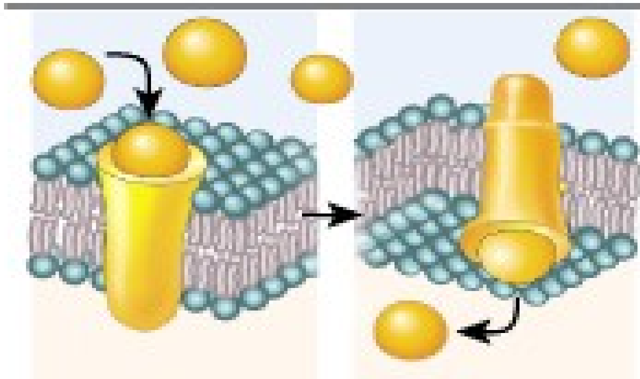
TRANSPORT

- Processes (at membrane)
  - Ion flow
  - Phagocytosis
  - Endocytosis
  - Exocytosis
- Mechanisms
  - Cilia
  - Microvilli

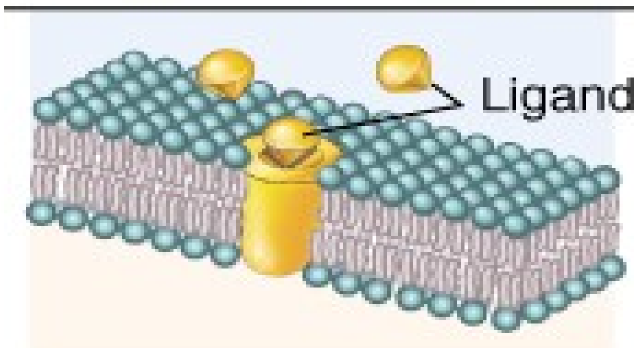
Extracellular fluid   Plasma membrane   Cytosol



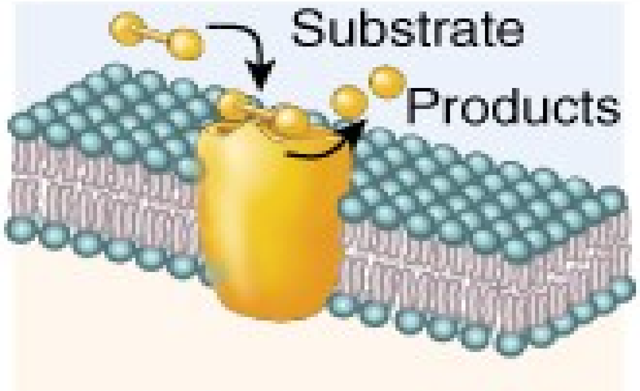
Channel
Allows specific substance (●) to move through water-filled pore. Most plasma membranes include specific channels for several common ions.



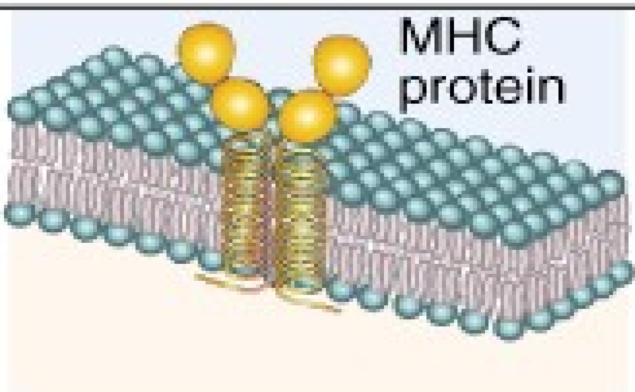
Transporter
Transports specific substances (●) across membrane by changing shape. For example, amino acids, needed to synthesize new proteins, enter body cells via transporters.



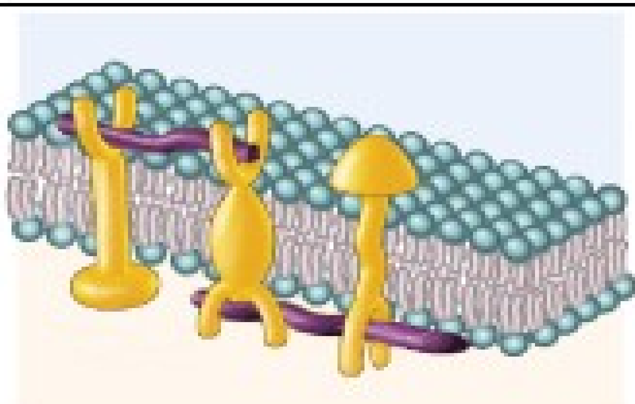
Receptor
Recognizes specific ligand (▼) and alters cell's function in some way. For example, antidiuretic hormone binds to receptors in the kidneys and changes the water permeability of certain plasma membranes.



Enzyme
Catalyzes reaction inside or outside cell (depending on which direction the active site faces). For example, lactase protruding from epithelial cells lining your small intestine splits the disaccharide lactose in the milk you drink.



Cell Identity Marker
Distinguishes your cells from anyone else's (unless you are an identical twin). An important class of such markers are the major histocompatability (MHC) proteins.



Linker
Anchors filaments inside and outside to the plasma membrane, providing structural stability and shape for the cell. May also participate in movement of the cell or link two cells together.

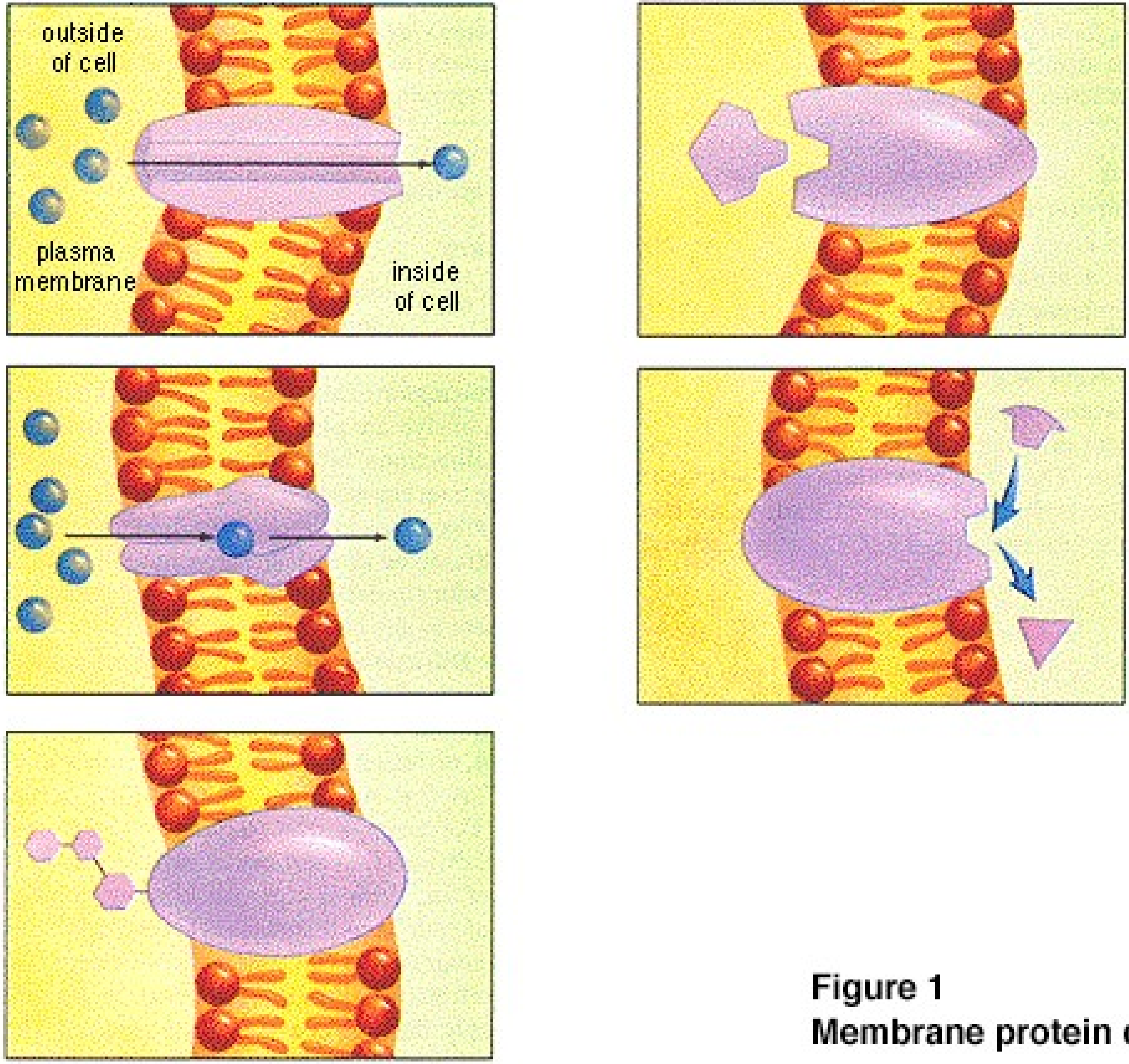


Figure 1
Membrane protein diversity.

EFFECTS OF MEMBRANE TRANSPORT

- “Things” are moved into and out of the cell as required
- Difference across the membrane
  - Charged molecules
    - => membrane “potential”

MEMBRANE TRANSPORT

- Passive transport (diffusion)
- Active transport
- Bulk transport
  - Exocytosis
  - Endocytosis

Membrane Permeability

- Plasma membranes are selectively permeable, meaning that some things can pass through and others cannot.
  - The lipid bilayer portion of the membrane is permeable to small, nonpolar, uncharged molecules but impermeable to ions and charged or polar molecules. It is also permeable to water.

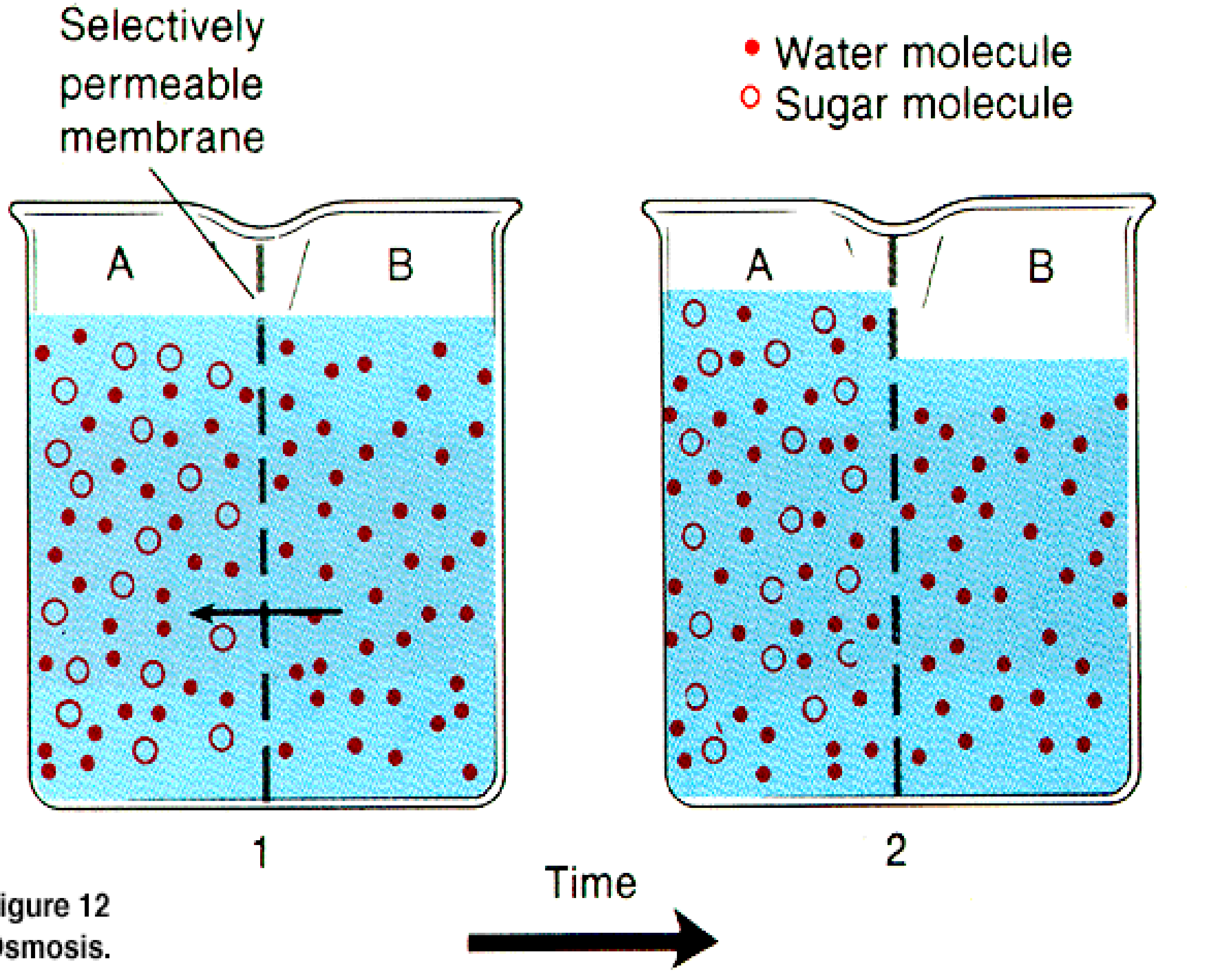


Figure 12
Osmosis.

Membrane Permeability

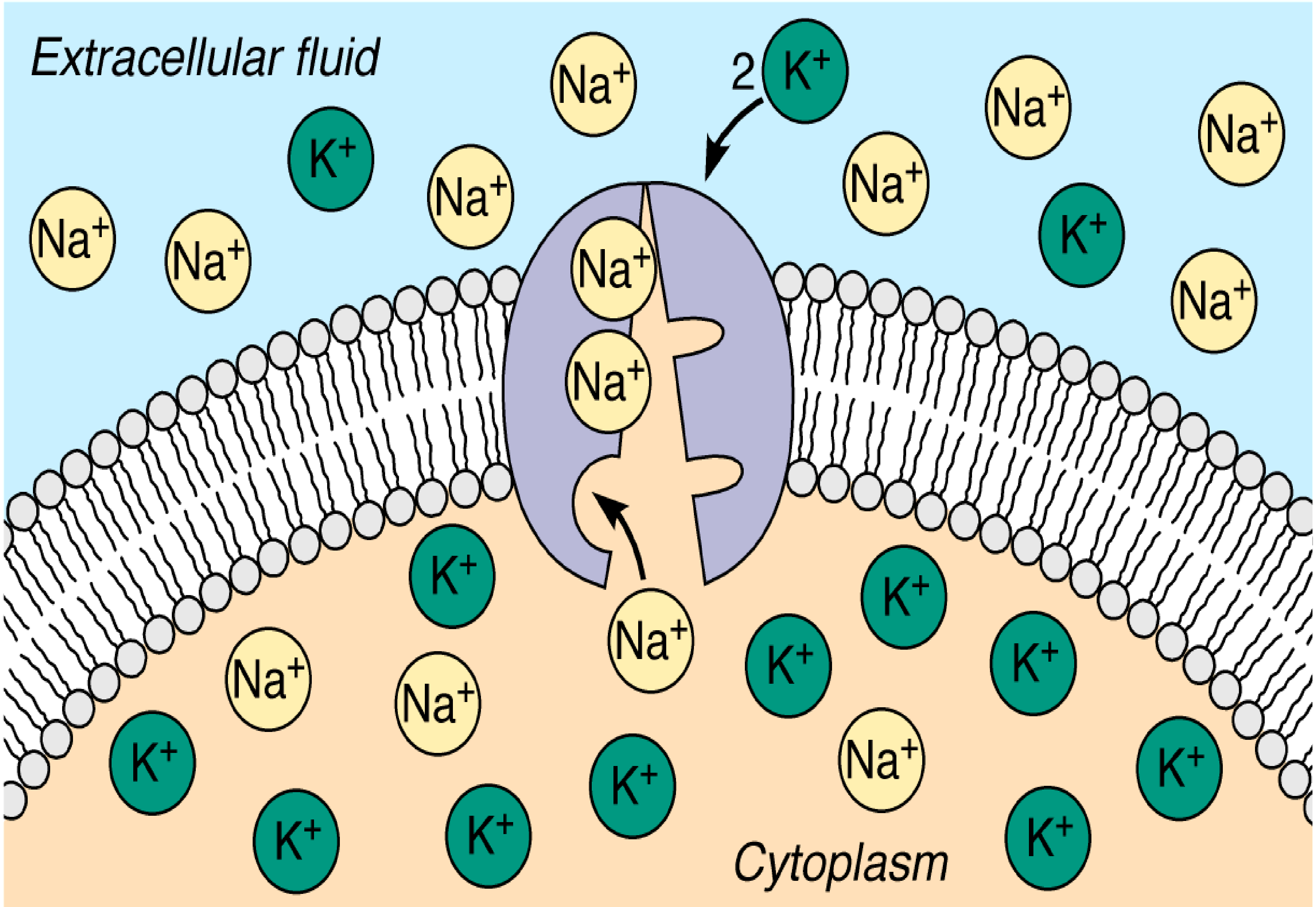
- Transmembrane proteins that act as channels or transporters increase the permeability of the membrane to molecules that cannot cross the lipid bilayer.
- Macromolecules are unable to pass through the plasma membrane except by vesicular transport.

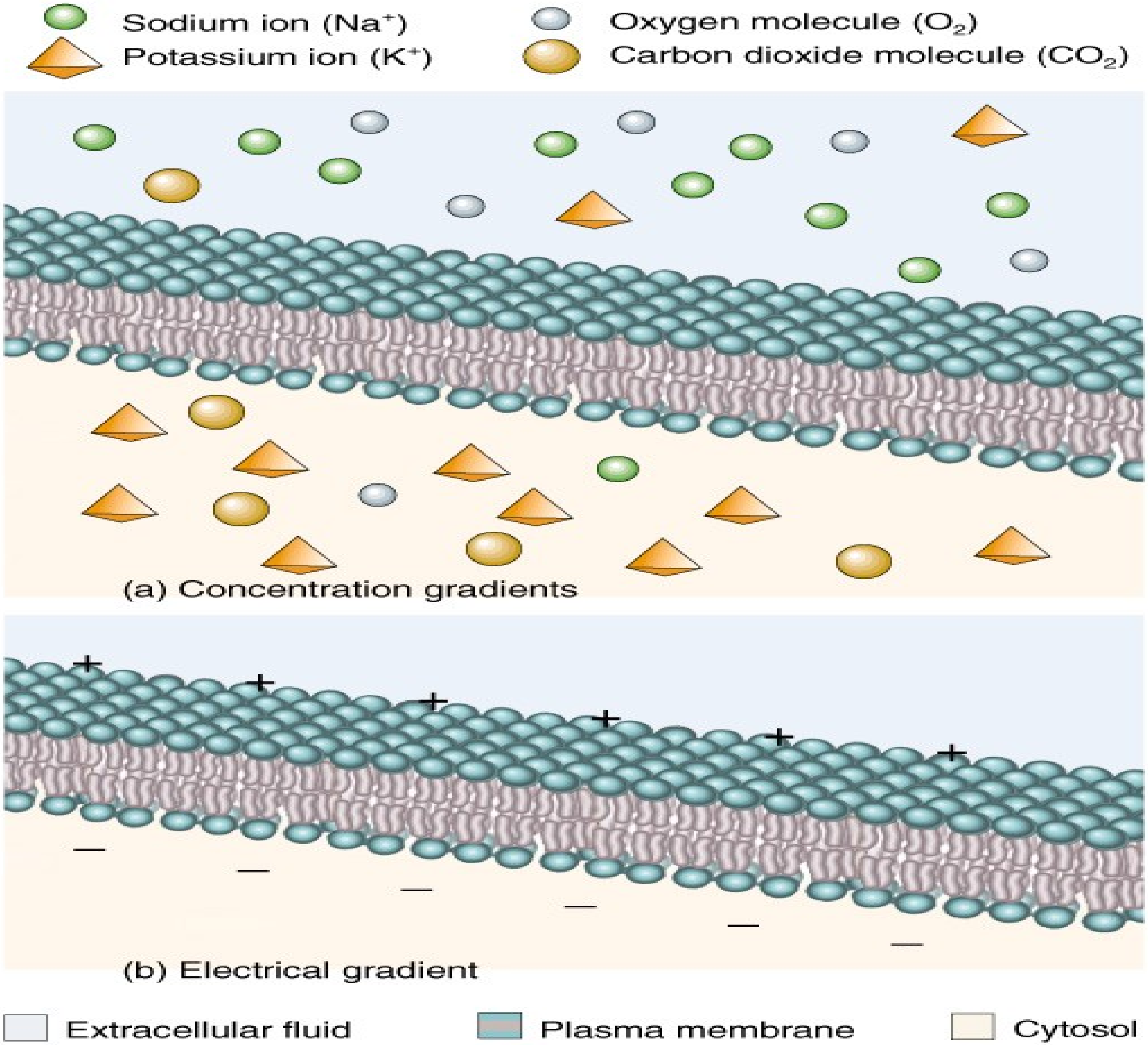
Gradients Across the Plasma Membrane

- A concentration gradient is the difference in the concentration of a chemical between one side of the plasma membrane and the other.
  - Oxygen and sodium ions are more concentrated outside the cell membrane with carbon dioxide and potassium ions more concentrated inside the cell membrane. (Fig. 3.4a).

Gradients Across the Plasma Membrane

- The inner surface of the membrane is more negatively charged and the outer surface is more positively charged (Fig. 3.4b).
- This sets up an electrical gradient, also called the ***membrane potential***.


Extracellular fluid
Na+
2 K+
K+
Na+
Na+
Na+
Na+
Na+
Na+
K+
Na+
Na+
Na+
K+
Na+
Na+
Na+
K+
K+
K+
K+
Na+
K+
K+
K+
K+
K+
Cytoplasm
K+



Sodium ion (Na^+)
Potassium ion (K^+)
Oxygen molecule (O_2)
Carbon dioxide molecule (CO_2)
(a) Concentration gradients
+
−
(b) Electrical gradient
Extracellular fluid
Plasma membrane
Cytosol

TRANSPORT ACROSS THE PLASMA MEMBRANE

- Processes to move substances across the cell membrane are essential to the life of the cell.
- Transport processes are classified according to two criteria: mediated or nonmediated and active or passive.

TRANSPORT ACROSS THE PLASMA MEMBRANE

- *Mediated transport* involves materials moving through the membrane with the assistance of a transporter protein.
- *Nonmediated transport* does not require a transporter protein.

TRANSPORT ACROSS THE PLASMA MEMBRANE

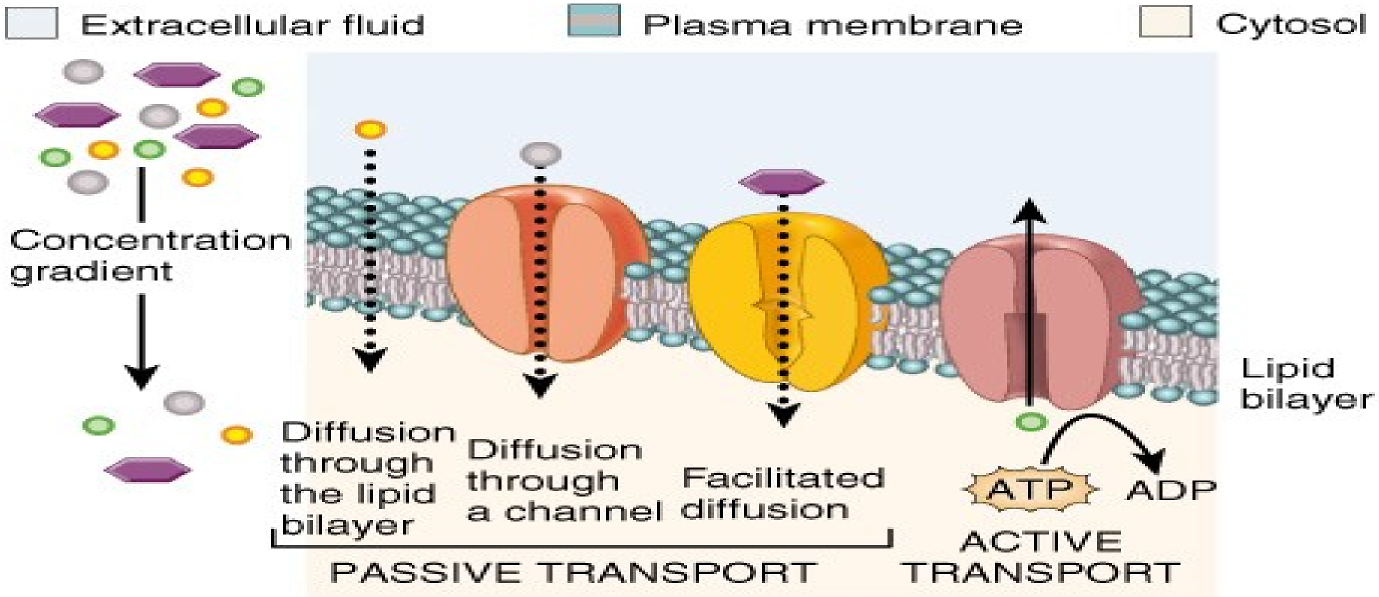
- In *passive transport*, a substance uses its own kinetic energy to move down a concentration gradient.
- In *active transport*, a substance uses its kinetic energy and energy from ATP to move up a concentration gradient.

TRANSPORT ACROSS THE PLASMA MEMBRANE

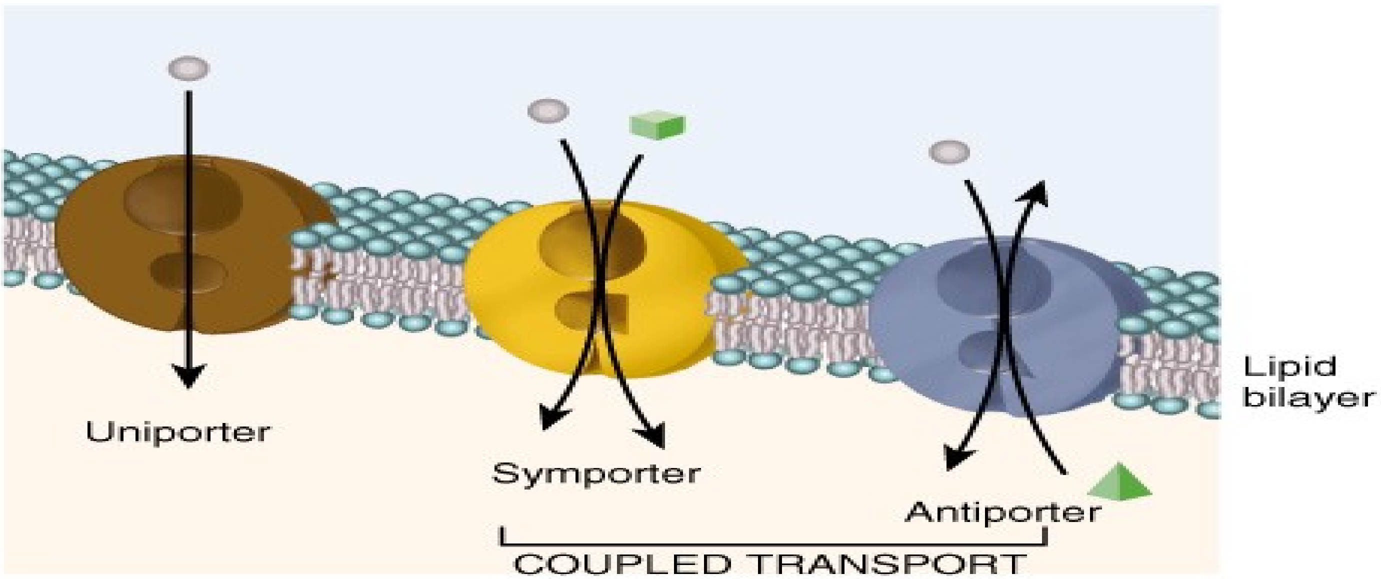
- Living cells use three passive transport processes, two of which are nonmediated (diffusion through the lipid bilayer and diffusion through a channel) and one that is mediated (facilitated diffusion).
- Living cells use mediated active processes distinguished by the types of transporters.

TRANSPORT ACROSS THE PLASMA MEMBRANE

- Uniporters move only a single substance across the membrane.
- Coupled transporters move two substances across the membrane and are either symporters or antiporters.
- Vesicular transport involves the formation of membrane-surrounded vesicles to move materials into or out of the cell by **endocytosis** or **exocytosis**.



(a) Passive and active transport

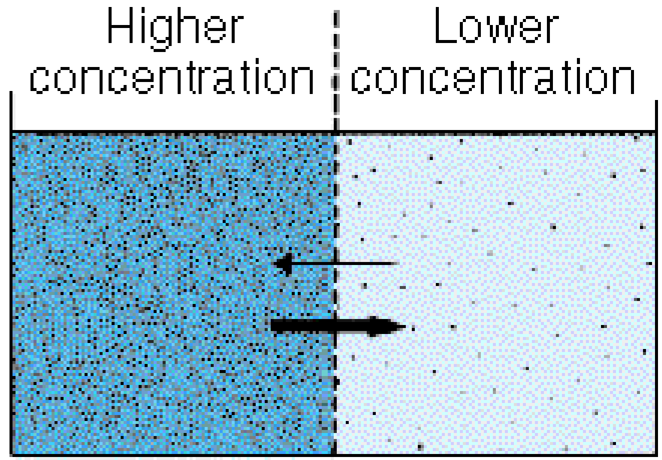


(b) Types of transporters in mediated transport

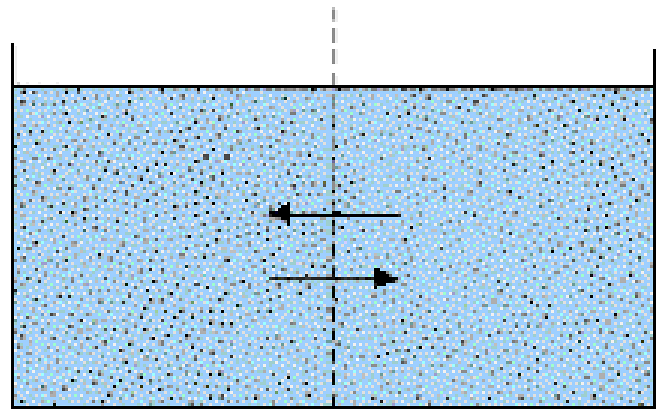
Principles of Diffusion

- *Diffusion* is the random mixing of particles that occurs in a solution as a result of the kinetic energy of the particles.
  - Diffusion rate across plasma membranes is influenced by several factors: steepness of the concentration gradient, temperature, size or mass of the diffusing substance, surface area, and diffusion distance.

Diffusion. Figure 6.1



Net diffusion



(b) No net diffusion

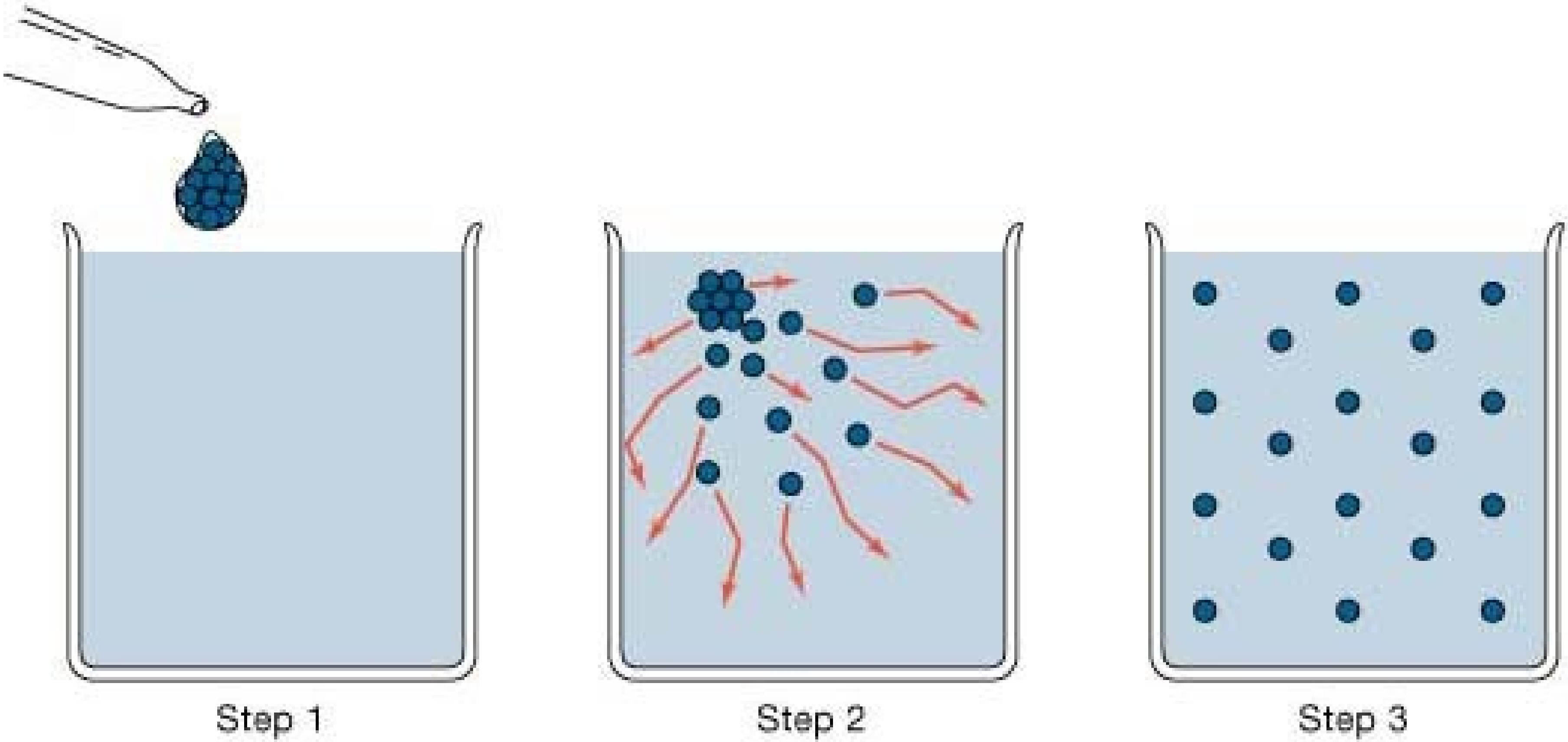


FIGURE 3-5 **Diffusion.** ***Step 1:*** Placing an ink drop in a glass of water establishes a strong concentration gradient because there are many ink molecules in one location and none elsewhere. ***Step 2:*** As diffusion occurs, the ink molecules spread through the solution. ***Step 3:*** Eventually, diffusion eliminates the concentration gradient, and the ink molecules are distributed evenly. Molecular motion continues, but there is no directional movement.

Figure 10
Diffusion in a container separated into two compartments.

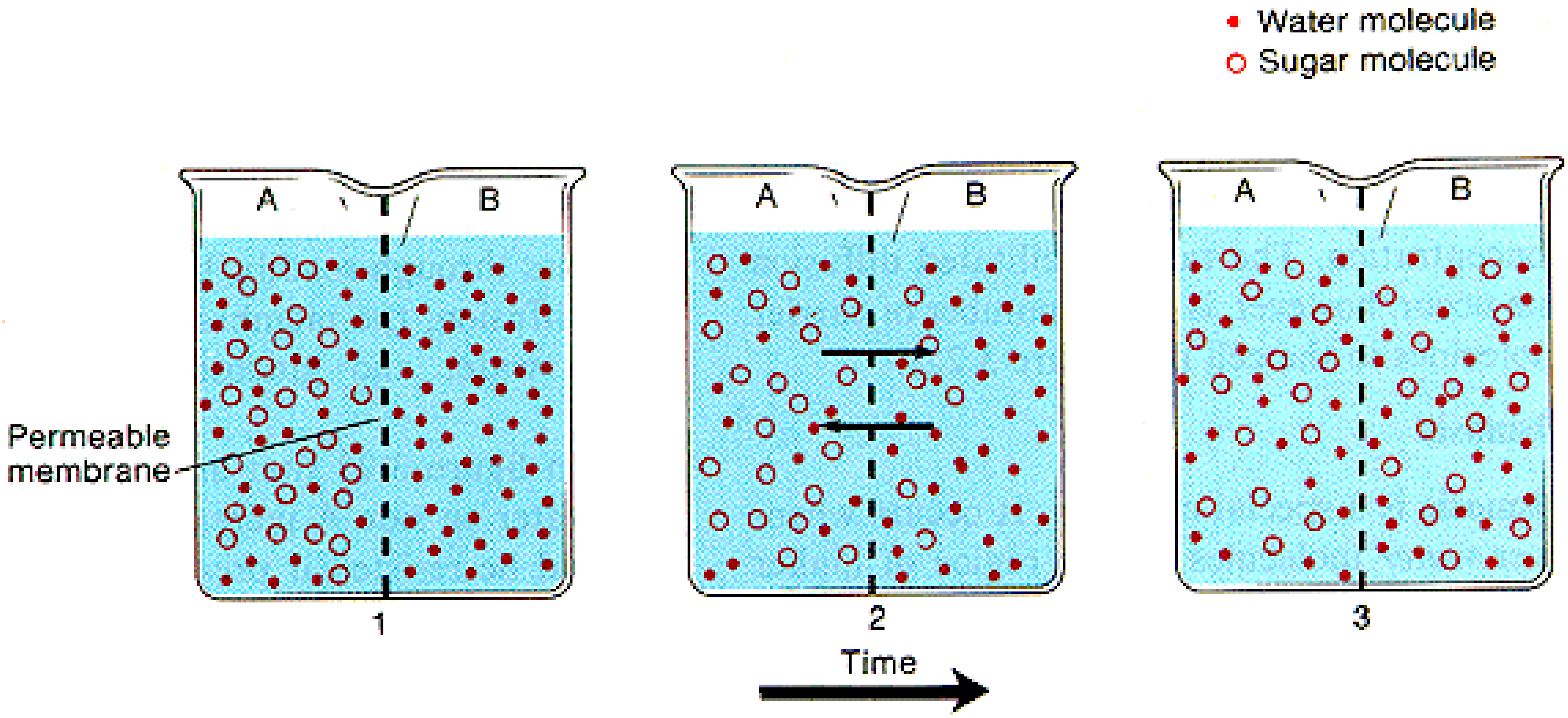


Figure 6 Semipermeable membrane (permeable to water but not to glucose, Na+, or Cl-).

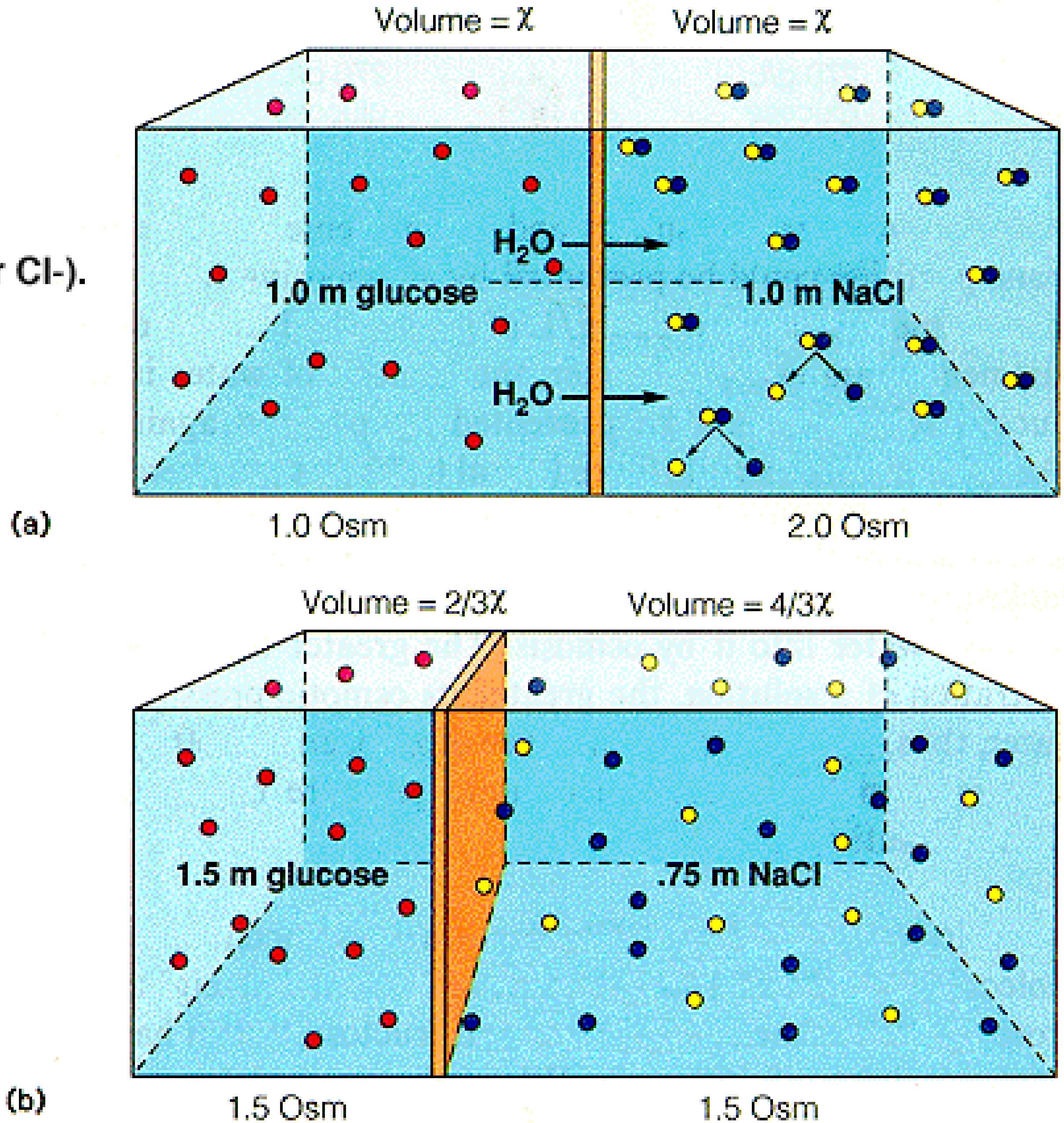
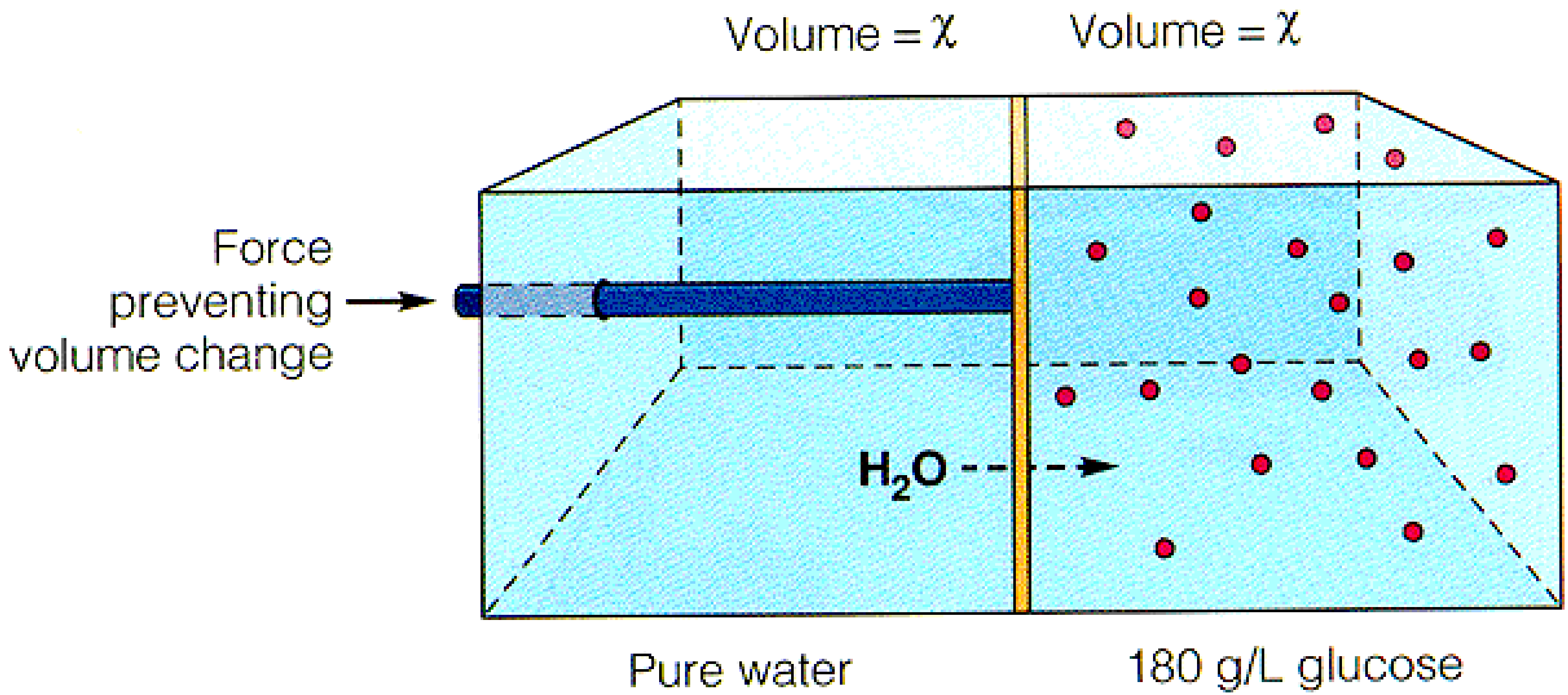


Figure 8
Semipermeable membrane separating water from a glucose solution.



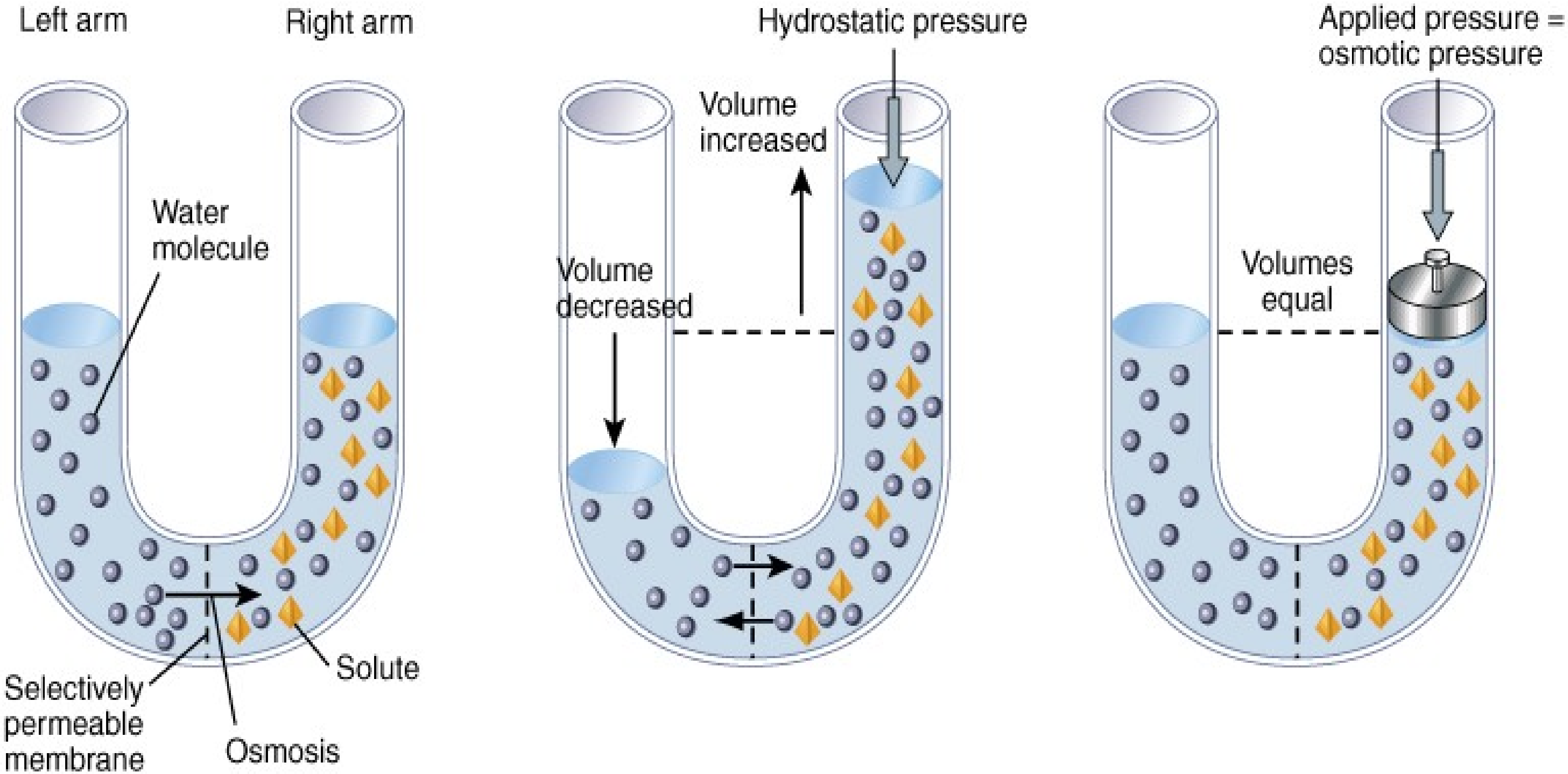
PRINCIPLES OF DIFFUSION

- ***Osmosis*** is the net movement of a solvent through a selectively permeable membrane, or in living systems, the movement of water (the solute) from an area of higher concentration to an area of lower concentration across the membrane (Fig. 3.7).

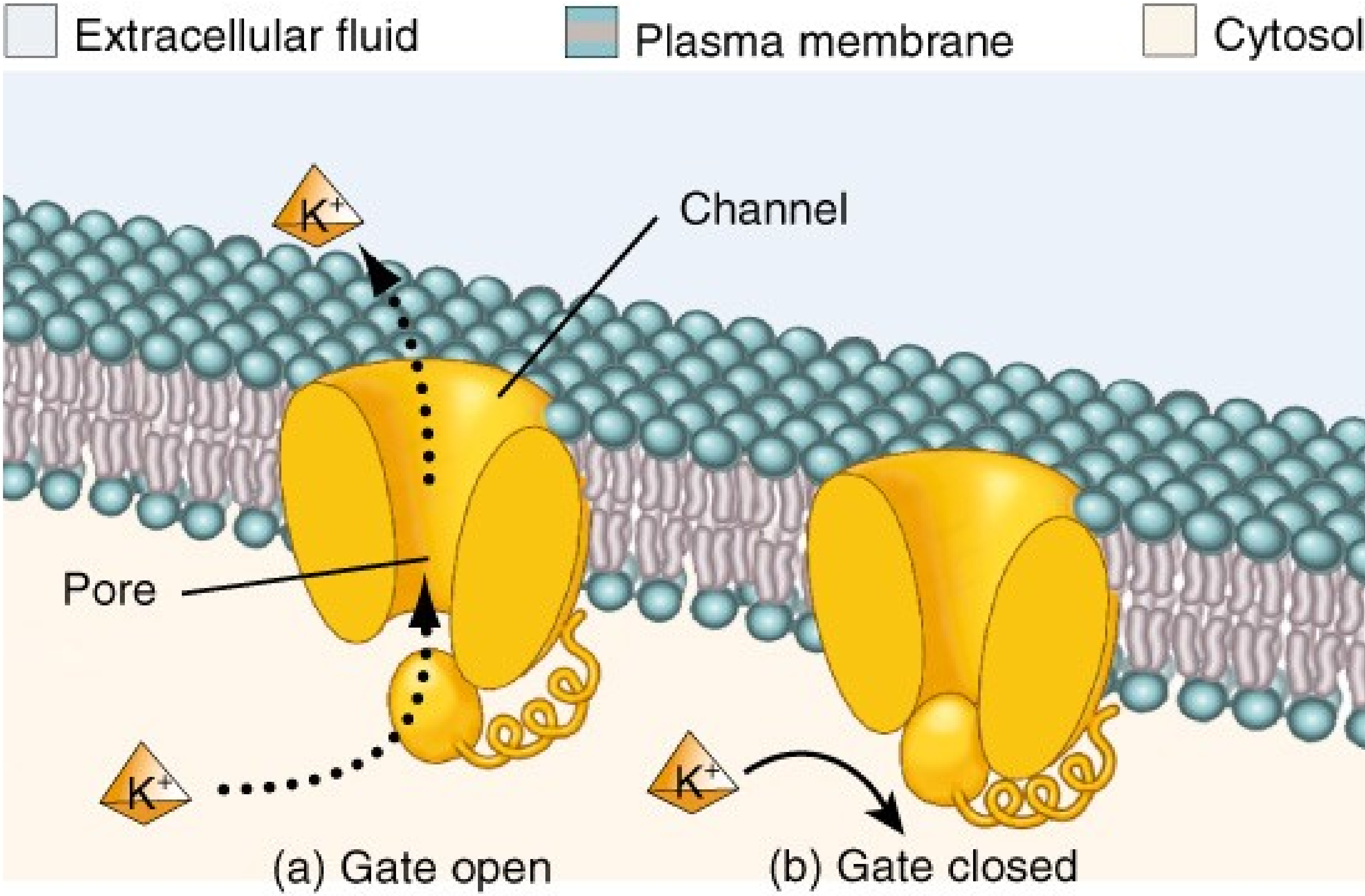
Osmosis

- Water molecules penetrate the membrane by diffusion through the lipid bilayer or through aquaporins, transmembrane proteins that function as water channels.
- Water moves from an area of lower solute concentration to an area of higher solute concentration.

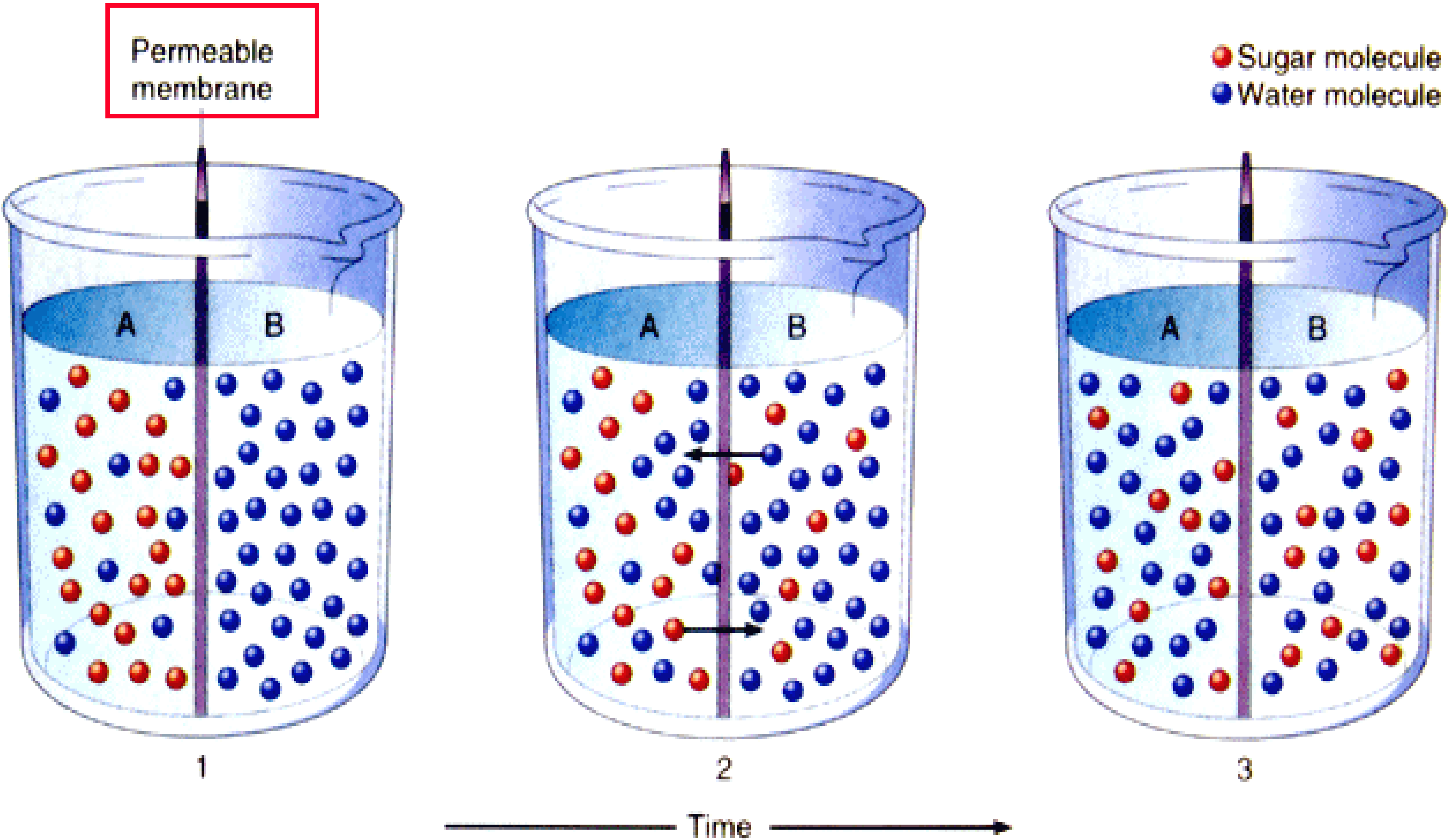
Osmosis



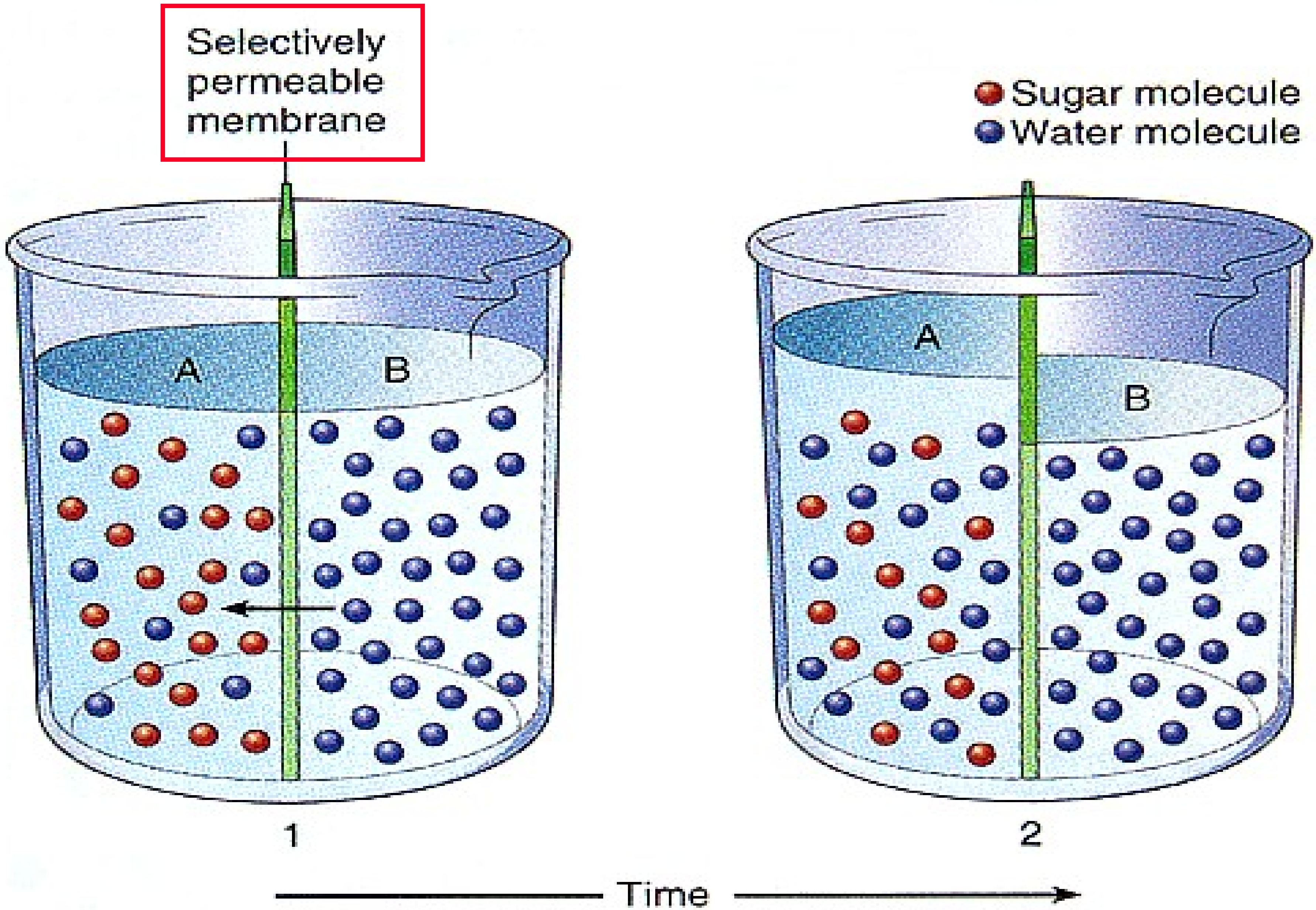
(a) Starting conditions (b) Equilibrium (c) Restoring starting conditions


Extracellular fluid
Plasma membrane
Cytosol
Channel
K^+
Pore
K^+
K^+
(a) Gate open
(b) Gate closed

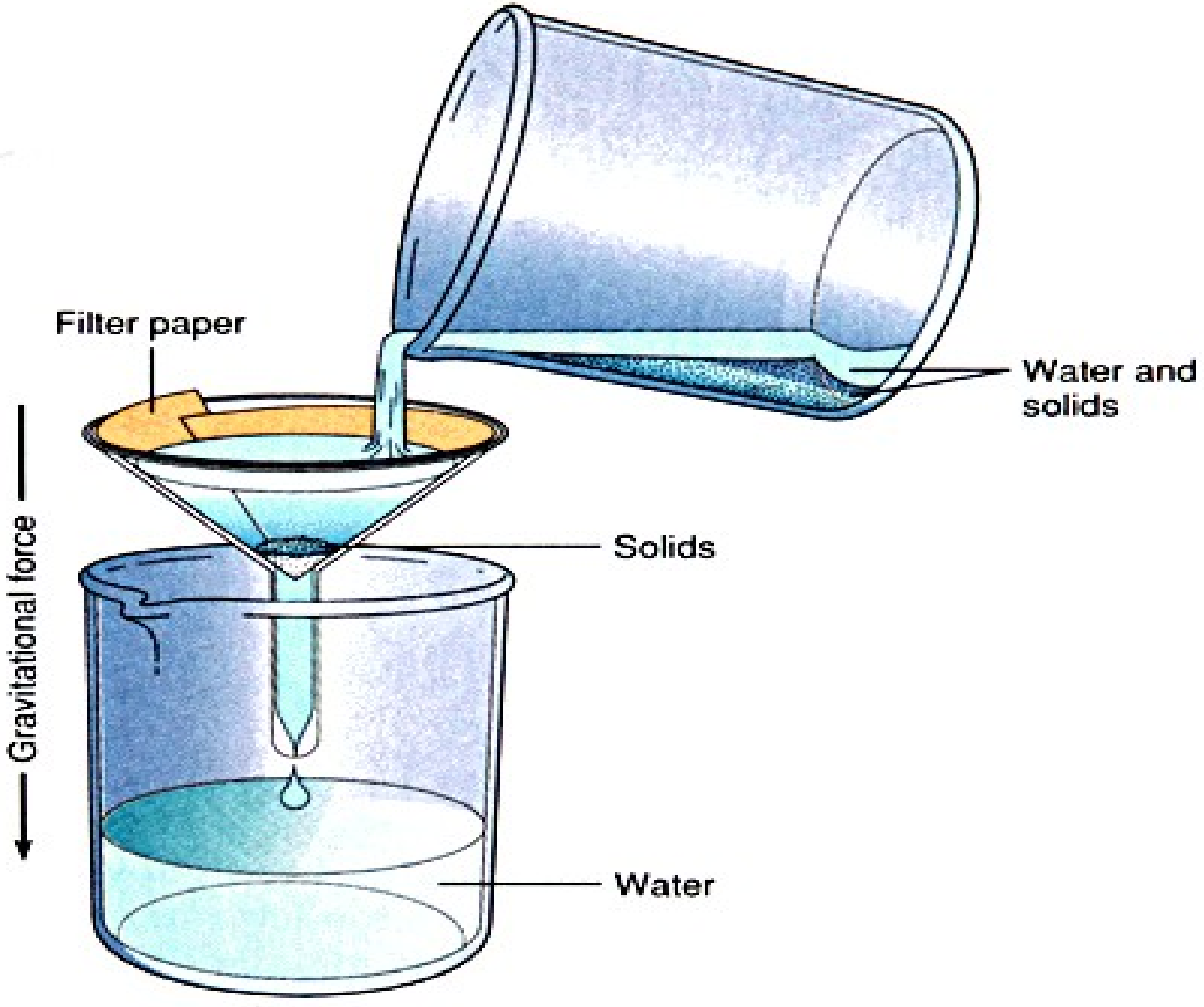
Molecular Motions.



Osmosis.


Selectively
permeable
membrane
Sugar molecule
Water molecule
A
B
A
B
1
2
Time

Filtration.


Filter paper
Water and solids
Gravitational force
Solids
Water

Osmosis

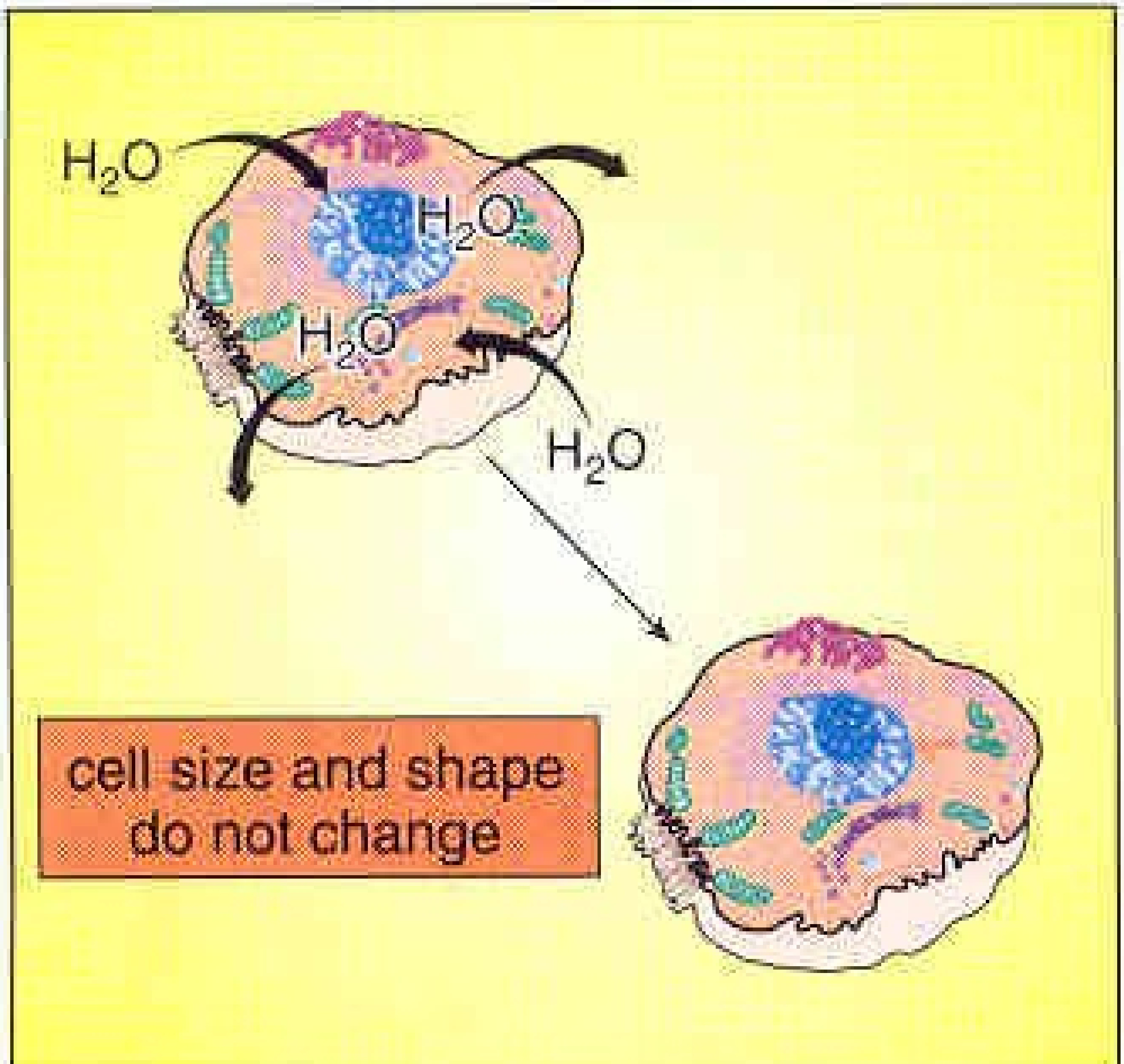
- Osmosis occurs only when the membrane is permeable to water but not to certain solutes.
  - *Tonicity* of a solution relates to how the solution influences the shape of body cells.
  - In an *isotonic* solution, red blood cells maintain their normal shape (Fig. 3.8a).

Osmosis

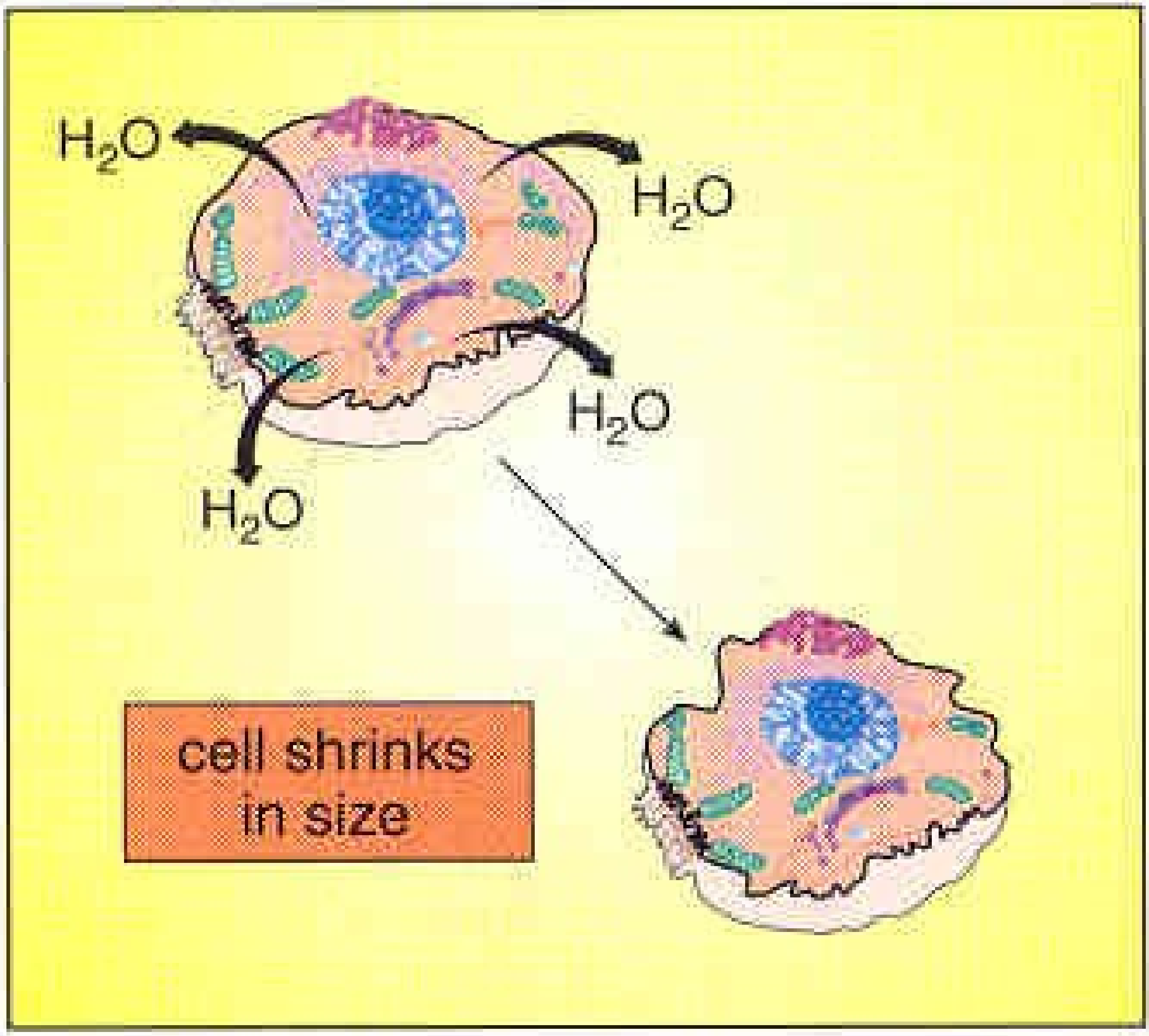
- In a *hypotonic* solution, red blood cells undergo hemolysis (Fig. 3.8b).
  - In a *hypertonic* solution, red blood cells undergo cremation (Fig. 3.8c).

FIG. 1–25. A. Isotonic solutions. The cell retains its shape because the concentration of the solute is equal inside and outside the cell. **B.** Hypertonic solutions. The cell shrinks (crenates) because there is a higher concentration of nonpenetrating solutes outside the cell membrane than inside. **C.** Hypotonic solution. The concentration of nondiffusible solutes in the solution is diluted compared to the concentration within the cell. The cell will take on water by osmosis, and can actually burst (lyse).

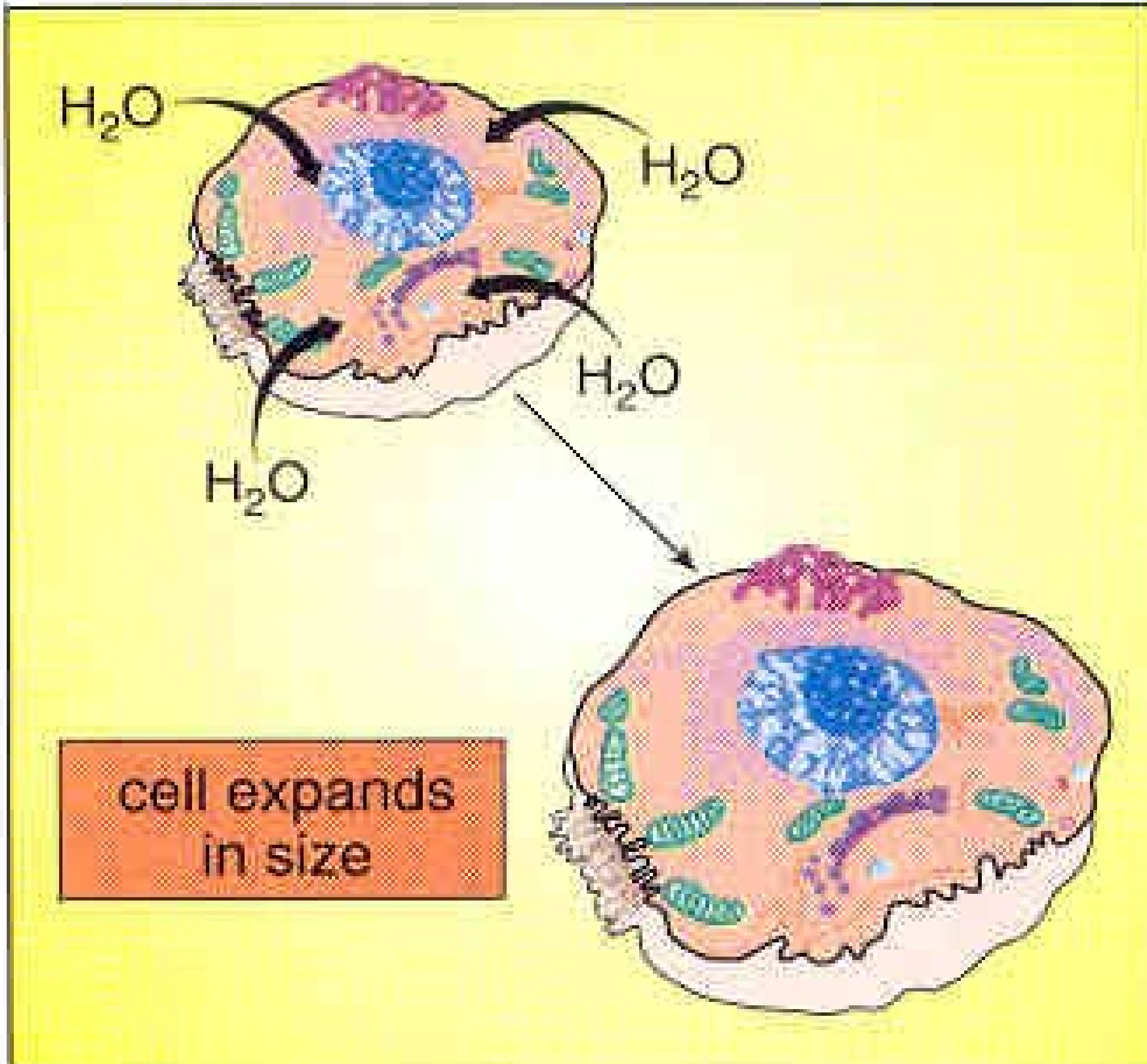
A. Isotonic solution



B. Hypertonic solution



C. Hypotonic solution



Diffusion Through the Lipid Bilayer

- Nonpolar, hydrophobic molecules such as respiratory gases, some lipids, small alcohols, and ammonia can diffuse across the lipid bilayer.
- It is important for gas exchange, absorption of some nutrients, and excretion of some wastes.

Diffusion Through Membrane Channels

- Most membrane channels are ion channels, allowing passage of small, inorganic ions which are hydrophilic.
- Ion channels are selective and specific and may be gated or open all the time (Fig. 3.9).

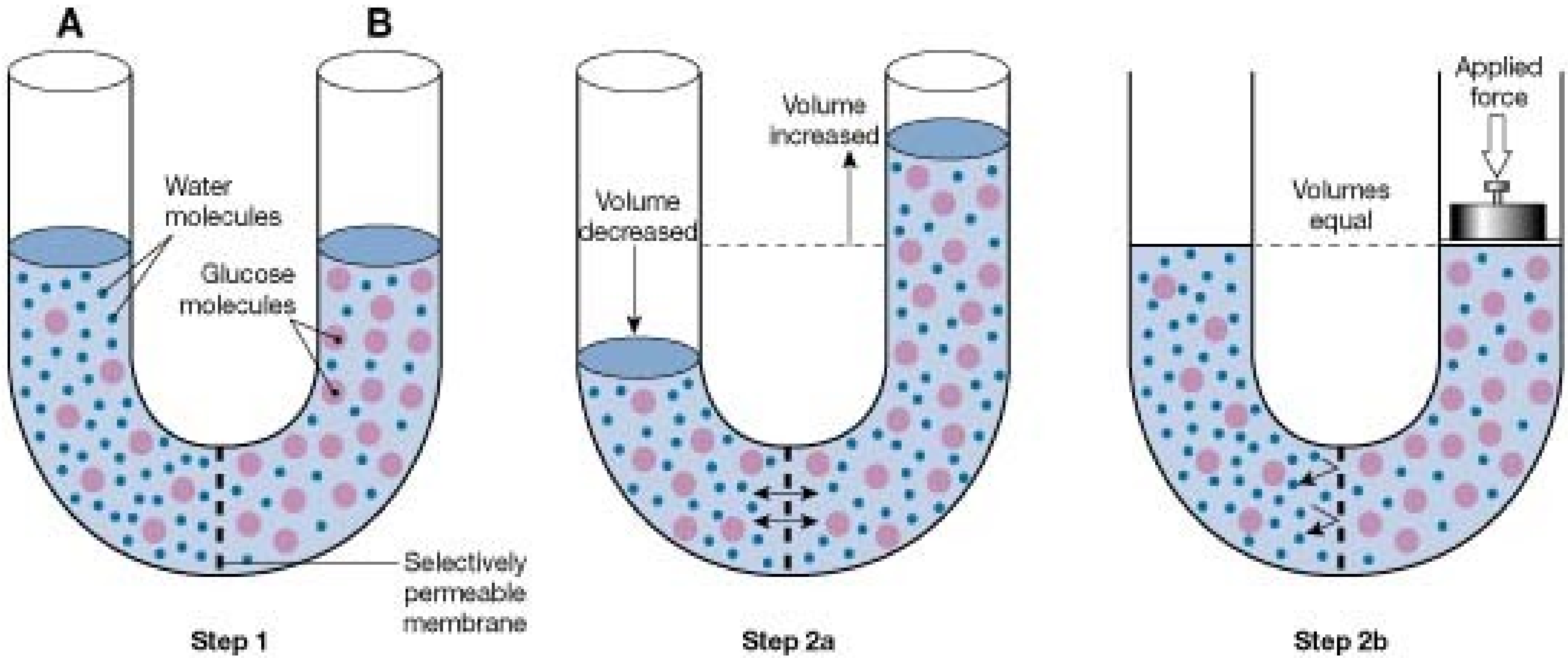
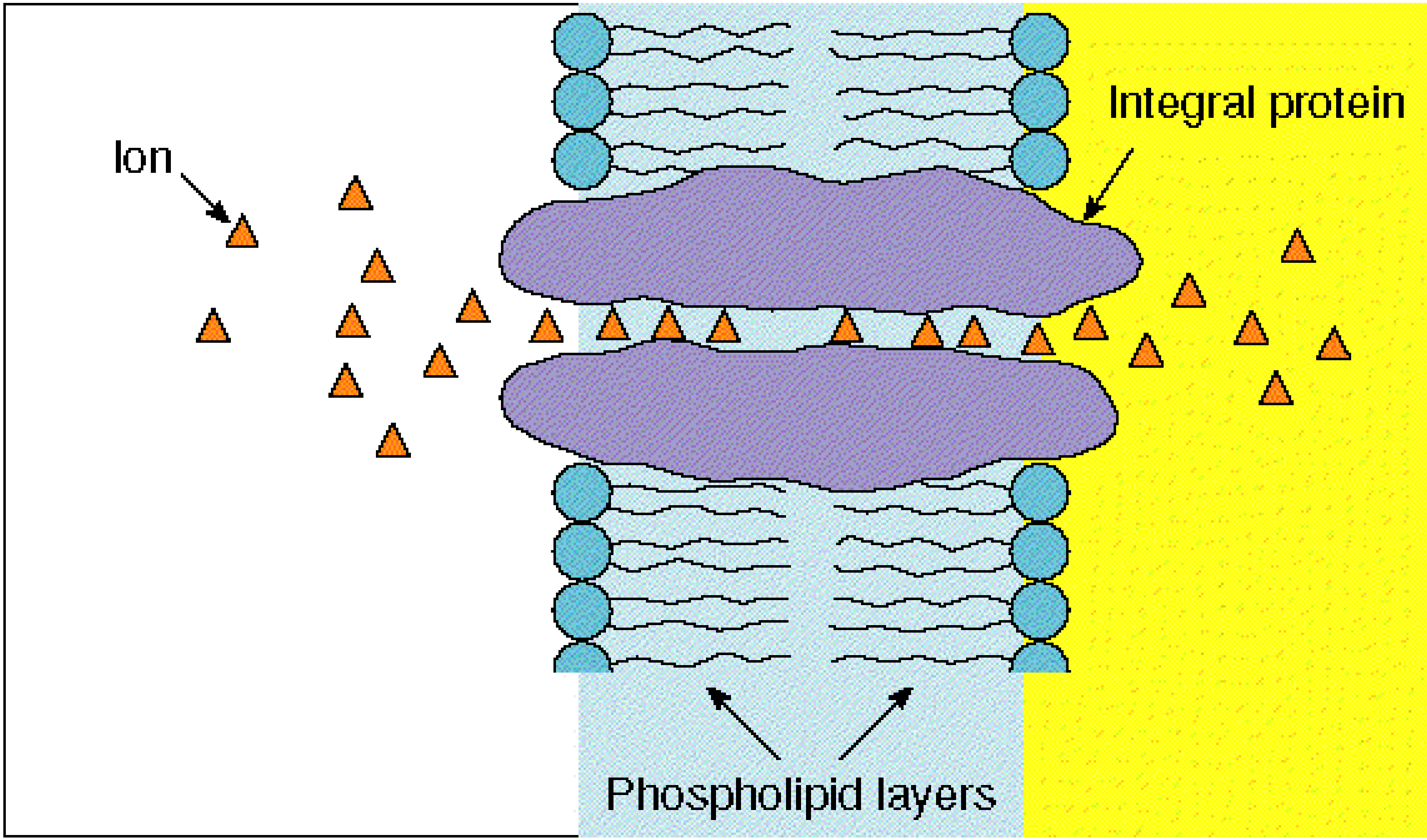
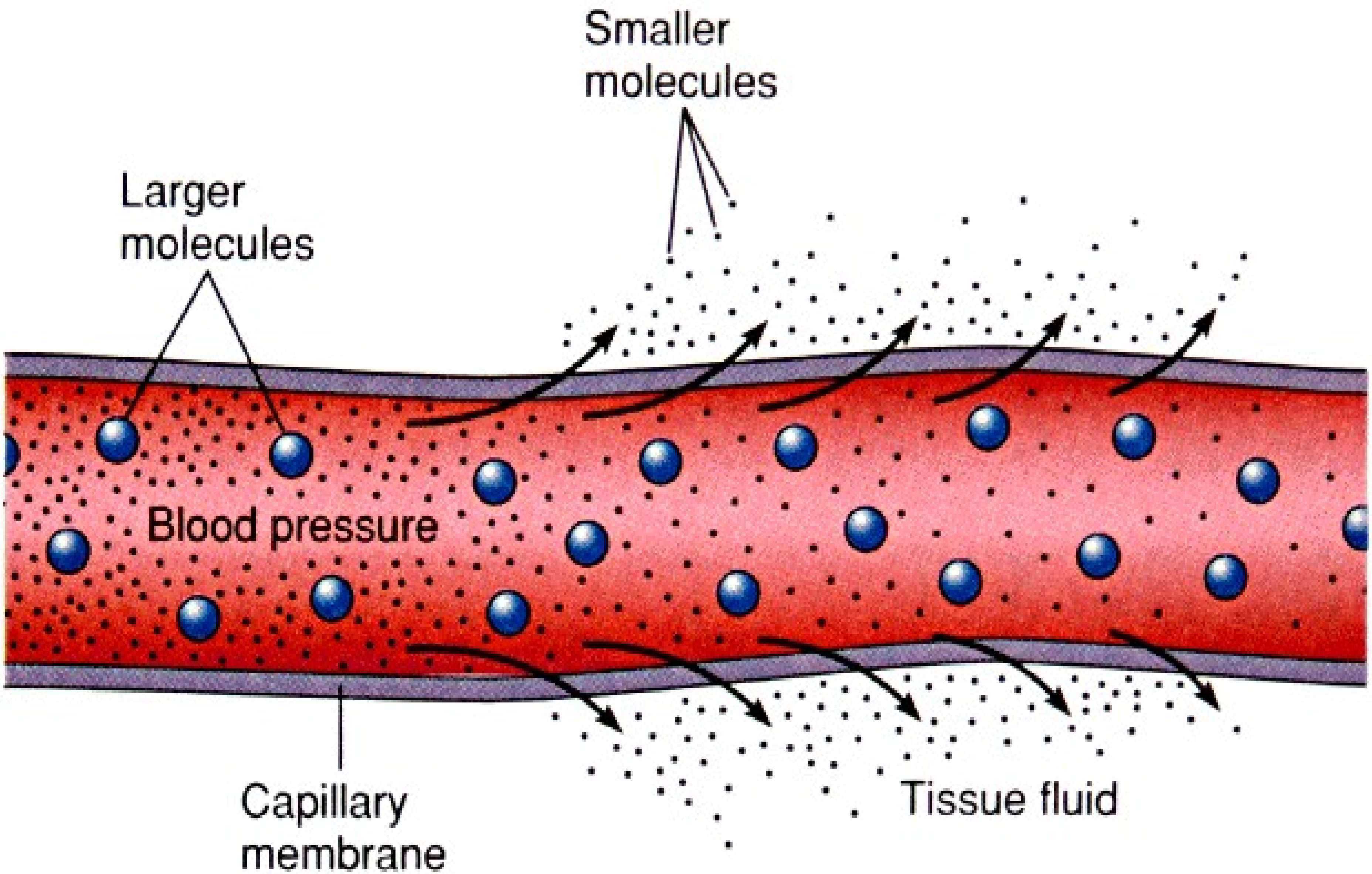


FIGURE 3-7 **Osmosis.** ***Step 1:*** Two solutions containing different solute concentrations are separated by a selectively permeable membrane. Water molecules (small blue dots) begin to cross the membrane toward solution B, the solution with the higher concentration of solutes (larger red circles). ***Step 2a:*** At equilibrium the solute concentrations on the two sides of the membrane are equal. The volume of solution B has increased at the expense of that of solution A. ***Step 2b:*** Osmosis can be prevented by resisting the volume change. The osmotic pressure of solution B is equal to the amount of hydrostatic pressure required to stop the osmotic flow.

Inorganic Ions. Figure 6.3



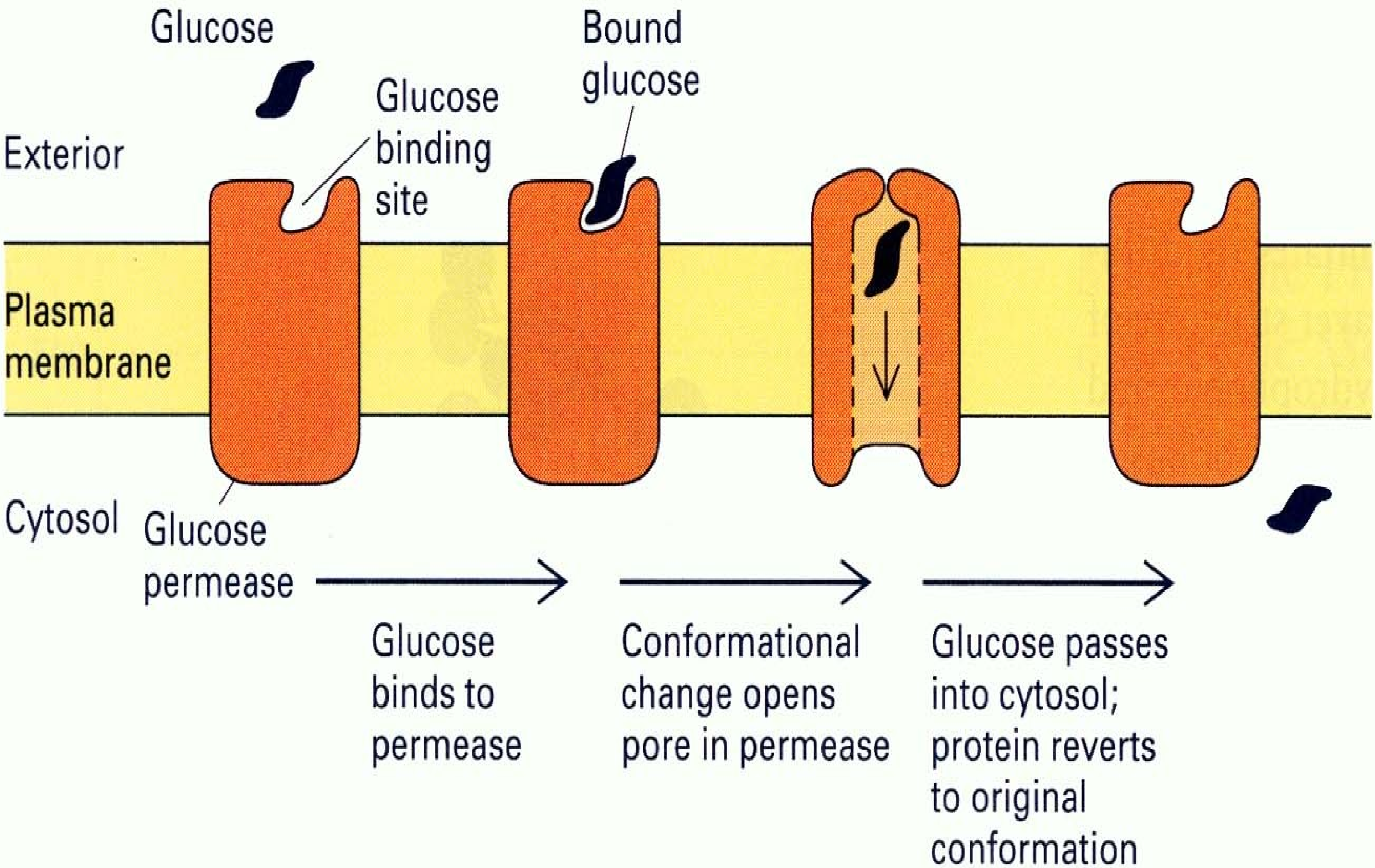
Filtration.

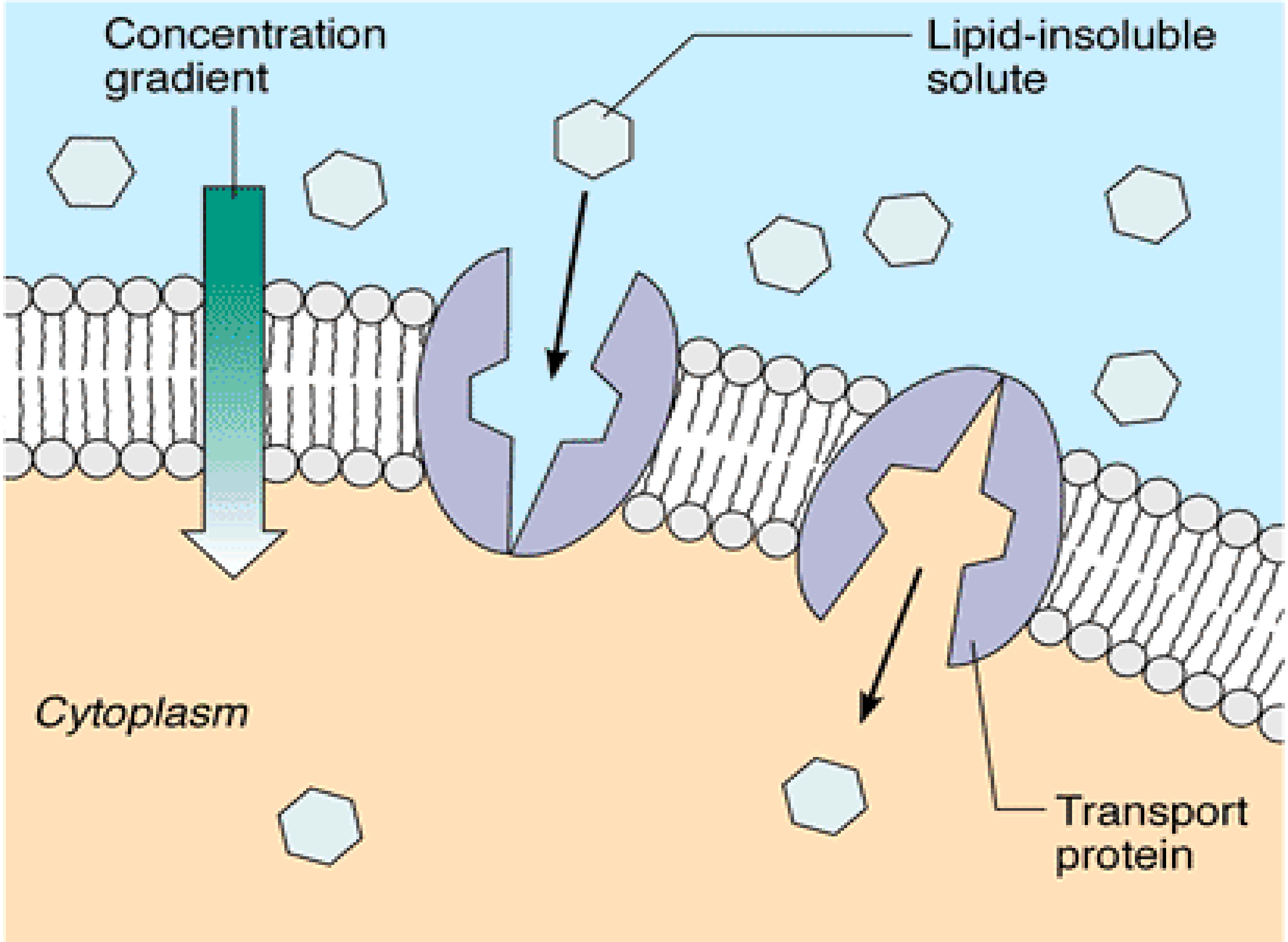


Smaller molecules
Larger molecules
Blood pressure
Capillary membrane
Tissue fluid

Facilitated Diffusion

- In *facilitated diffusion*, a solute binds to a specific transporter on one side of the membrane and is released on the other side after the transporter undergoes a conformational change.
  - Solutes that move across membranes by facilitated diffusion include **glucose**, urea, fructose, galactose, and some vitamins (Fig. 3.10).


Glucose
Bound glucose
Glucose binding site
Exterior
Plasma membrane
Cytosol
Glucose permease
Glucose binds to permease
Conformational change opens pore in permease
Glucose passes into cytosol; protein reverts to original conformation



(b) Facilitated diffusion

Facilitate Diffusion.

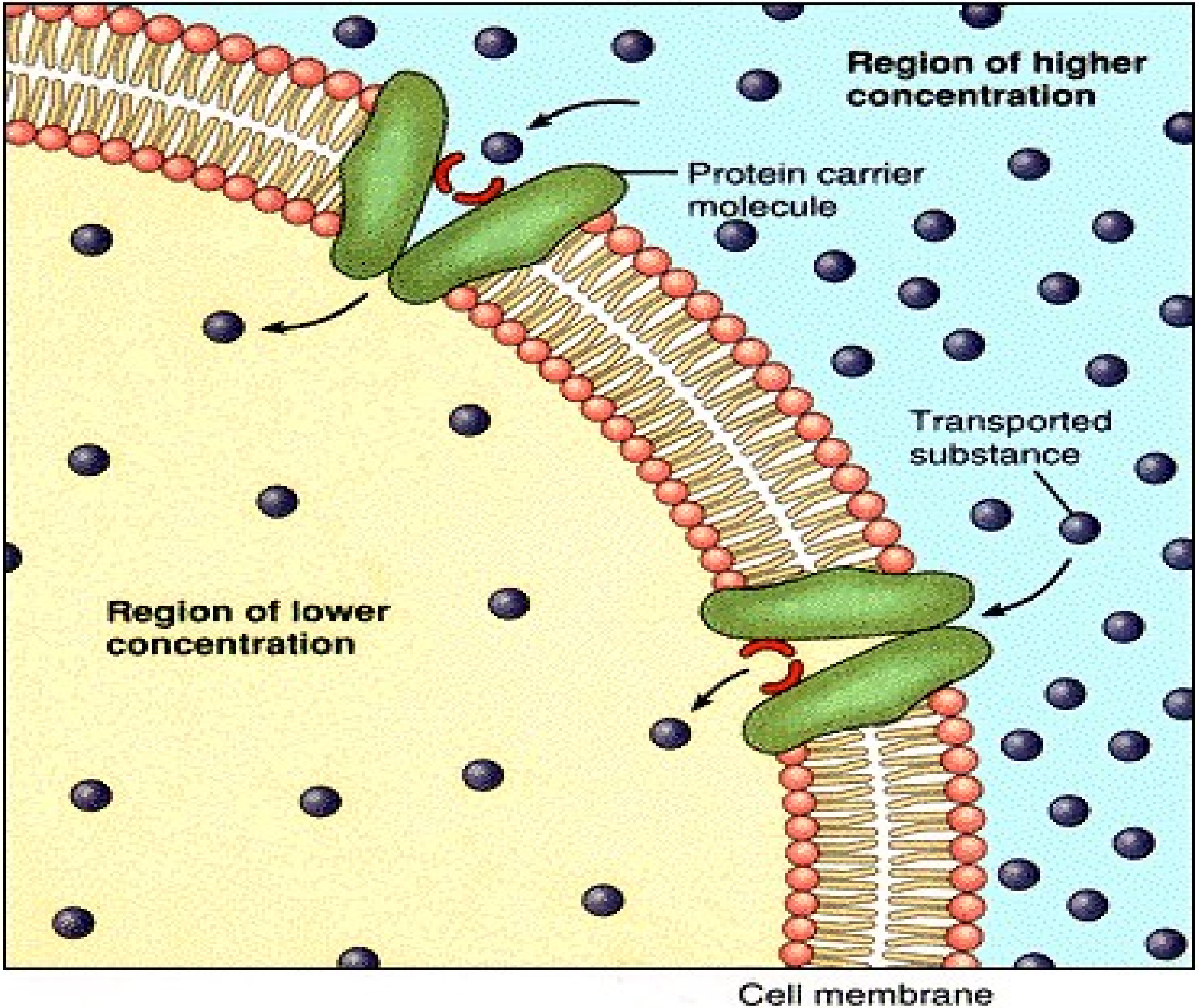
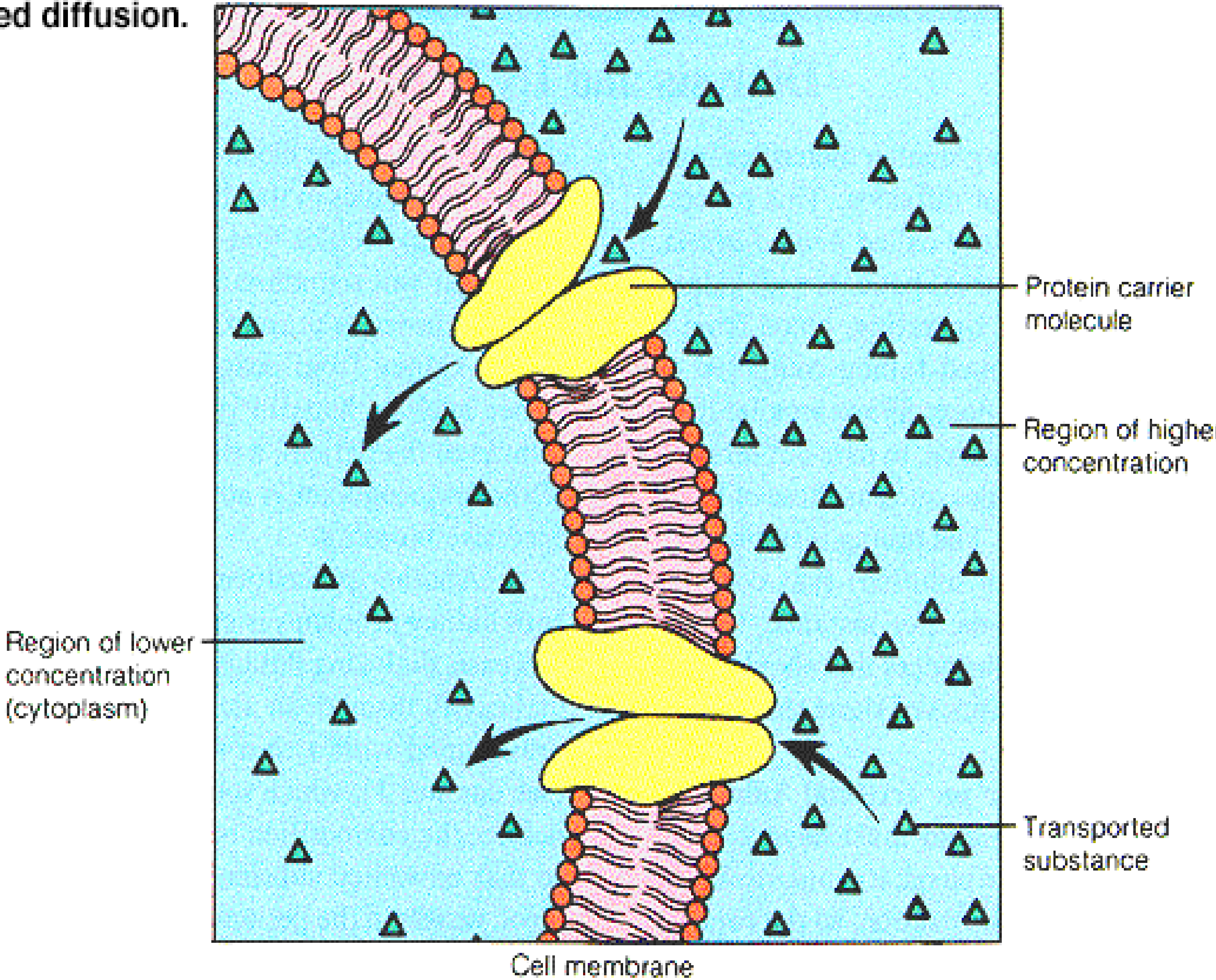


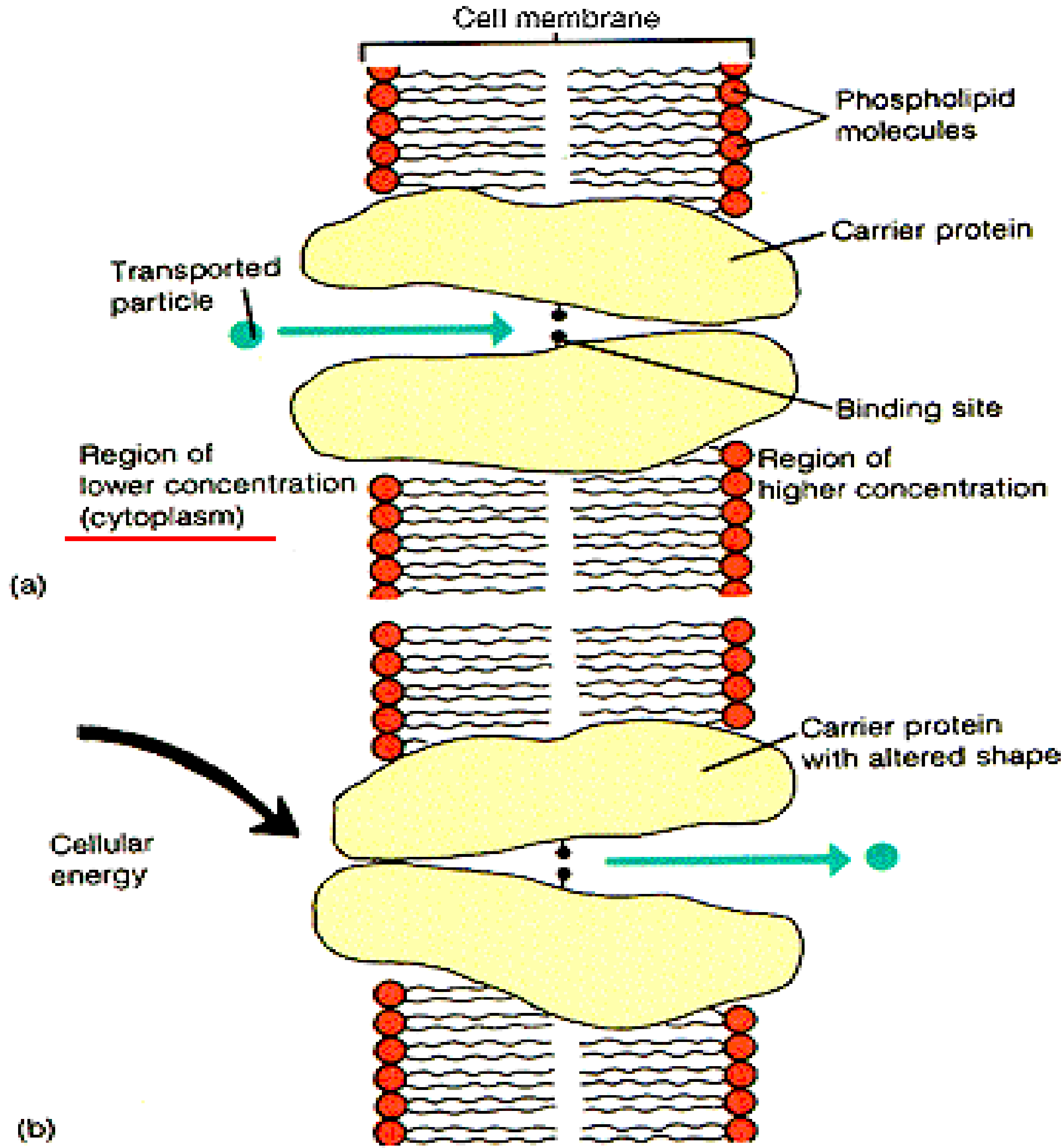
Figure 11
Facilitated diffusion.



Active Transport

- Active transport is an energy-requiring process that moves solutes such as ions, amino acids, and monosaccharides against a concentration gradient.
  - In *primary active transport*, energy derived from ATP changes the shape of a transporter protein, which pumps a substance across a plasma membrane against its concentration gradient.
  - The most prevalent primary active transport mechanism is the **sodium ion/potassium ion pump** (Fig. 3.11).

Figure 9
Active transport.



Active Transport.

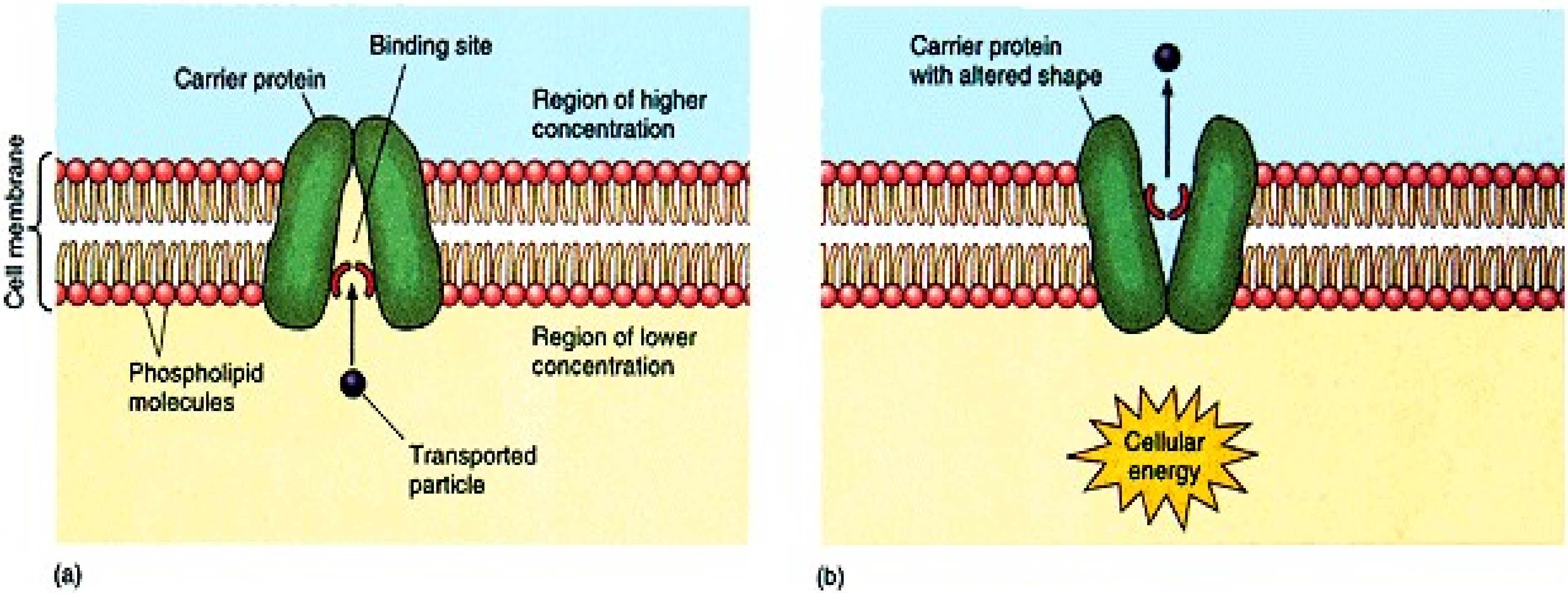


Figure 4
A model for the cotransport of Na+ and glucose into a cell.

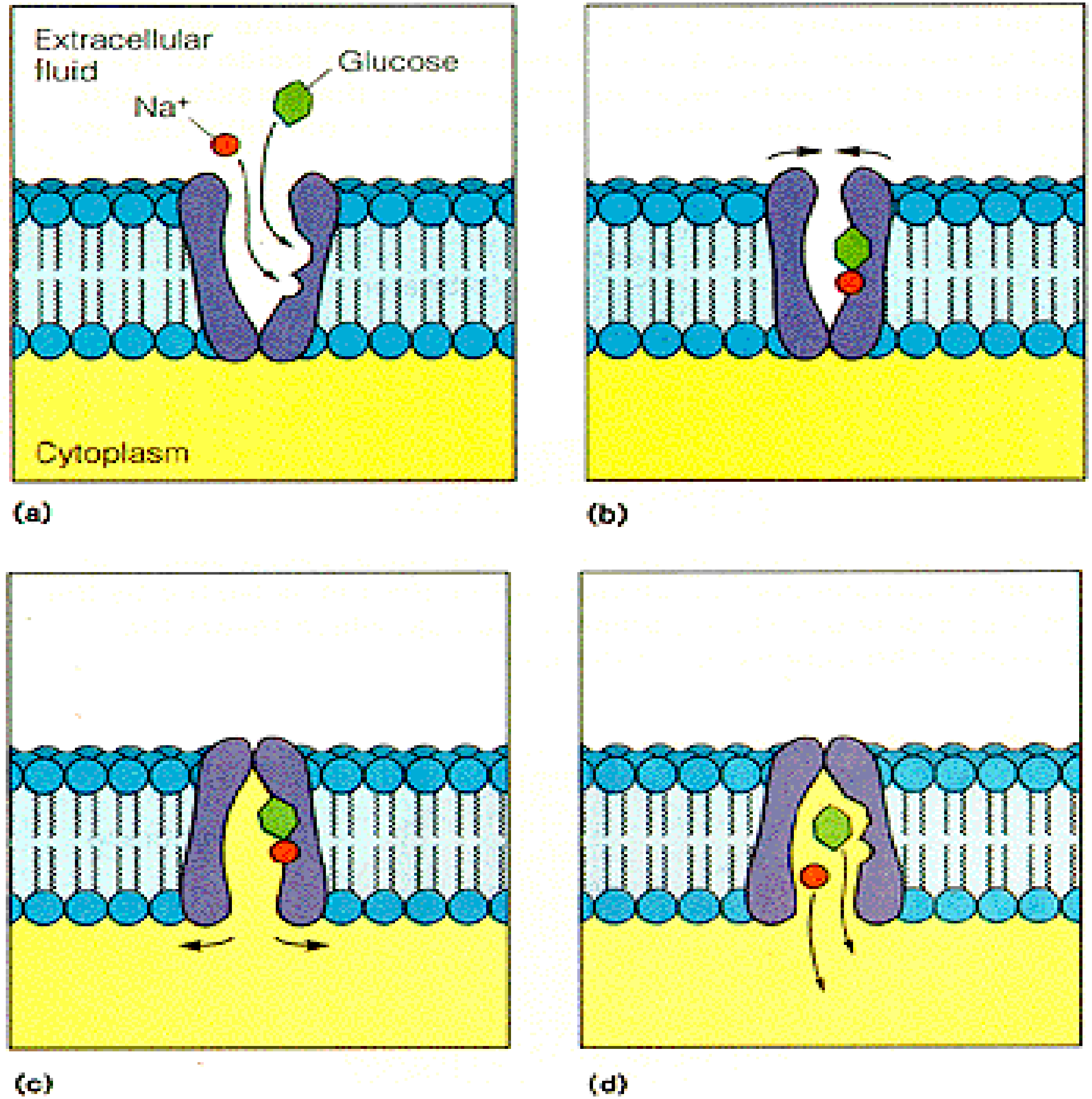


Figure 1
The sodium-potassium pump.

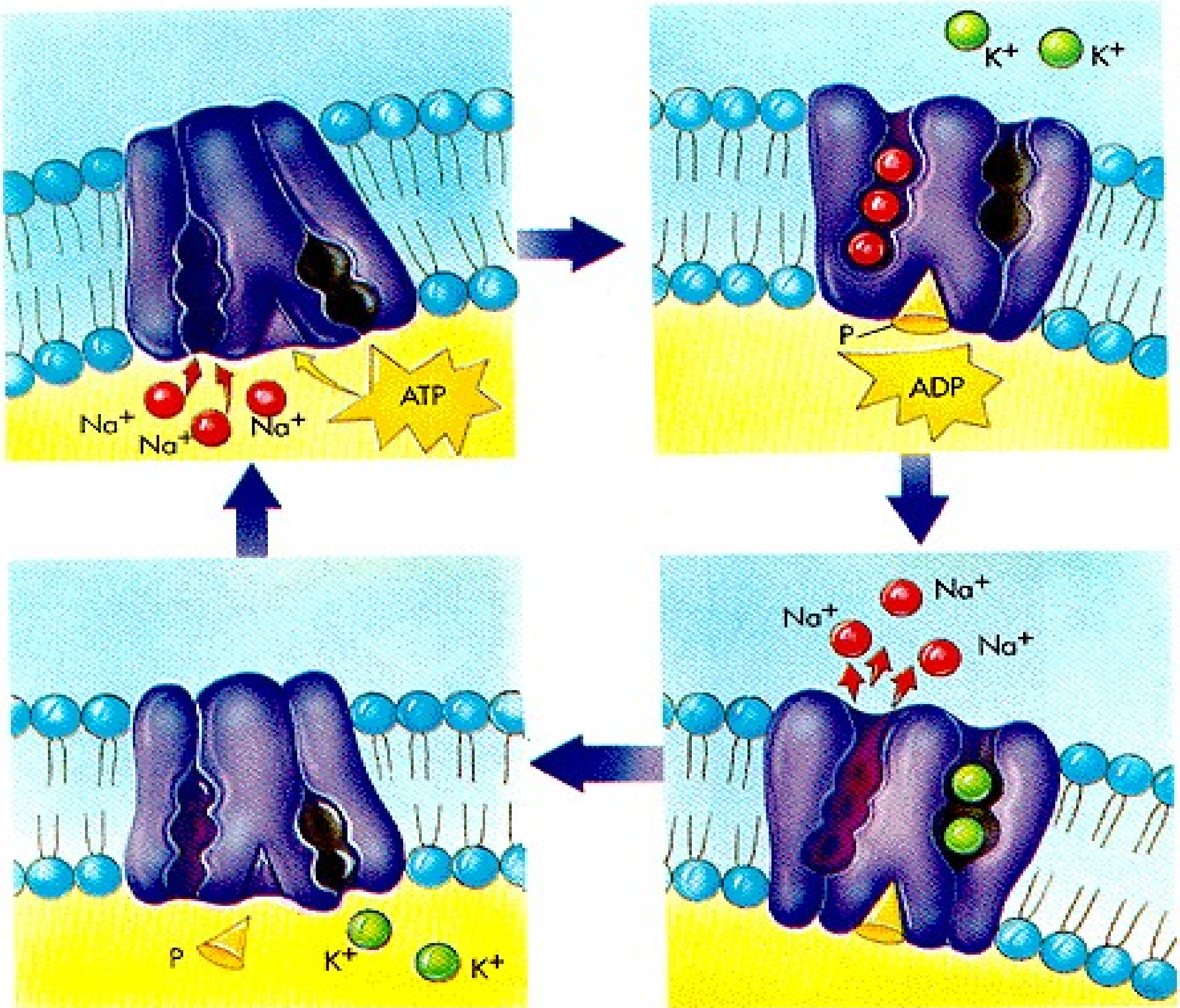
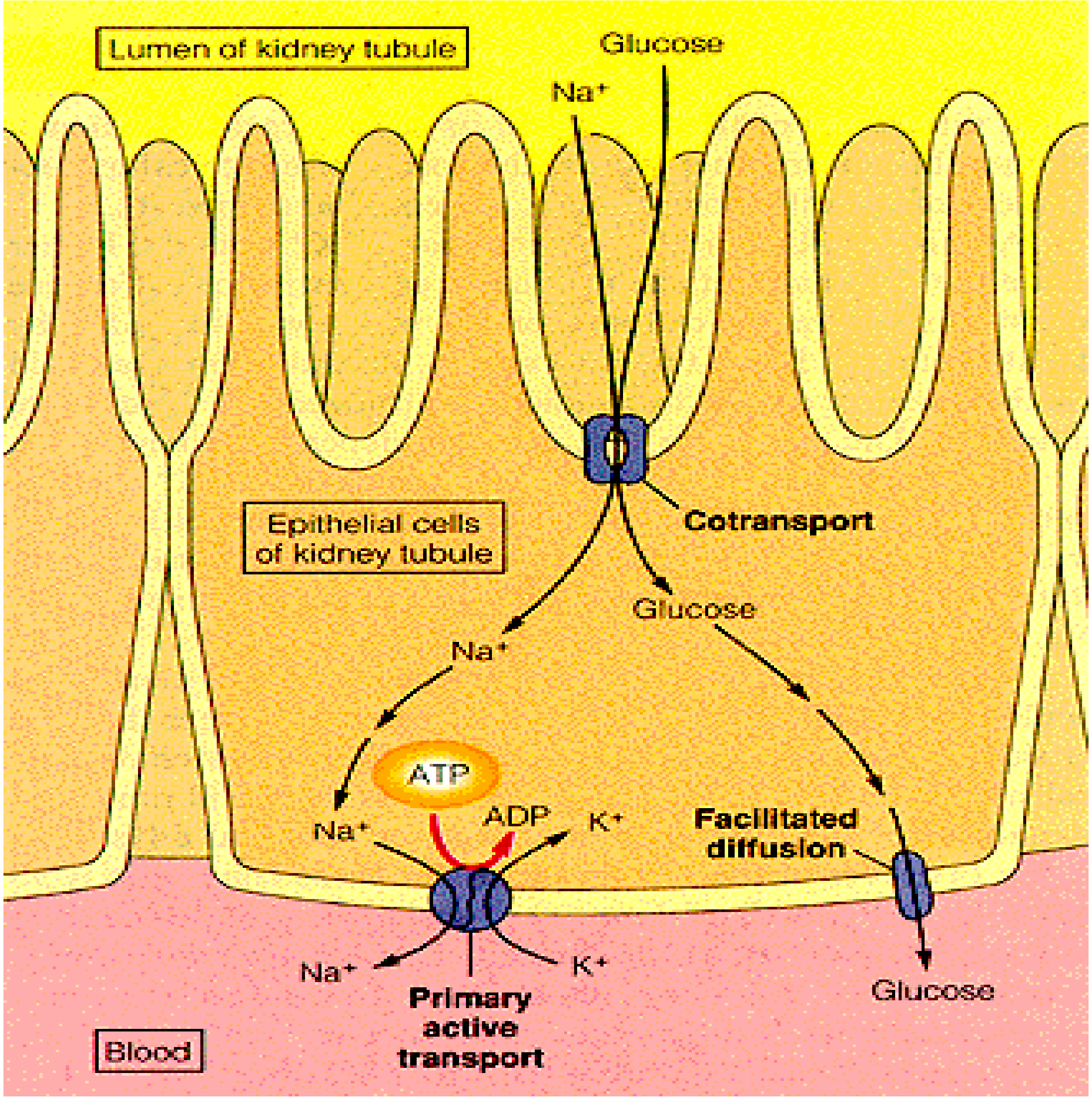


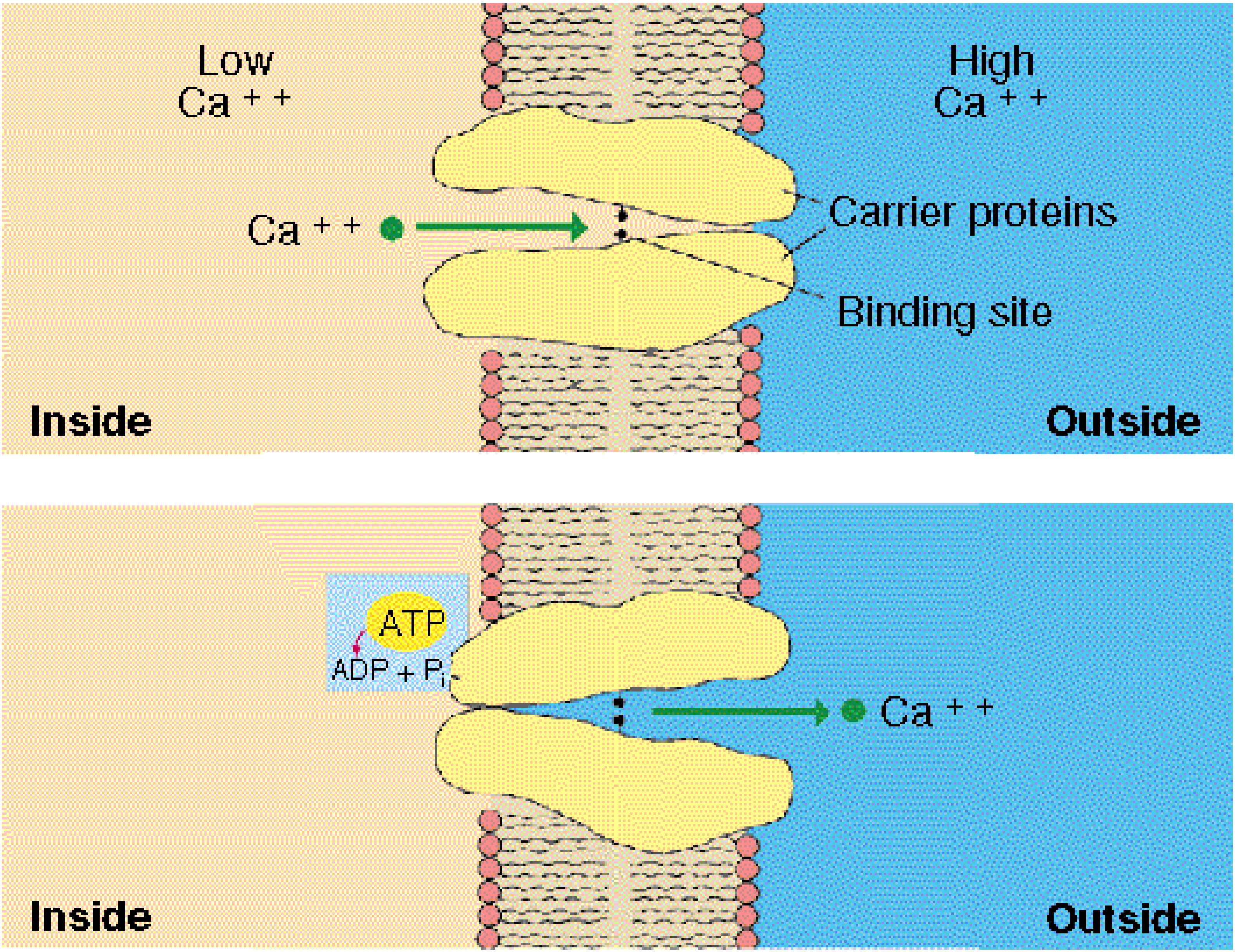
Figure 5
The transport of glucose from the fluid in the kidney tubules.



Secondary Active Transport

- In *secondary active transport*, the energy stored in the form of a sodium or hydrogen ion concentration gradient is used to drive other substances against their own concentration gradients.
  - Plasma membranes contain several antiporters and symporters powered by the sodium ion gradient (Fig. 3.12).

Model of Active Transport. Figure 6.14



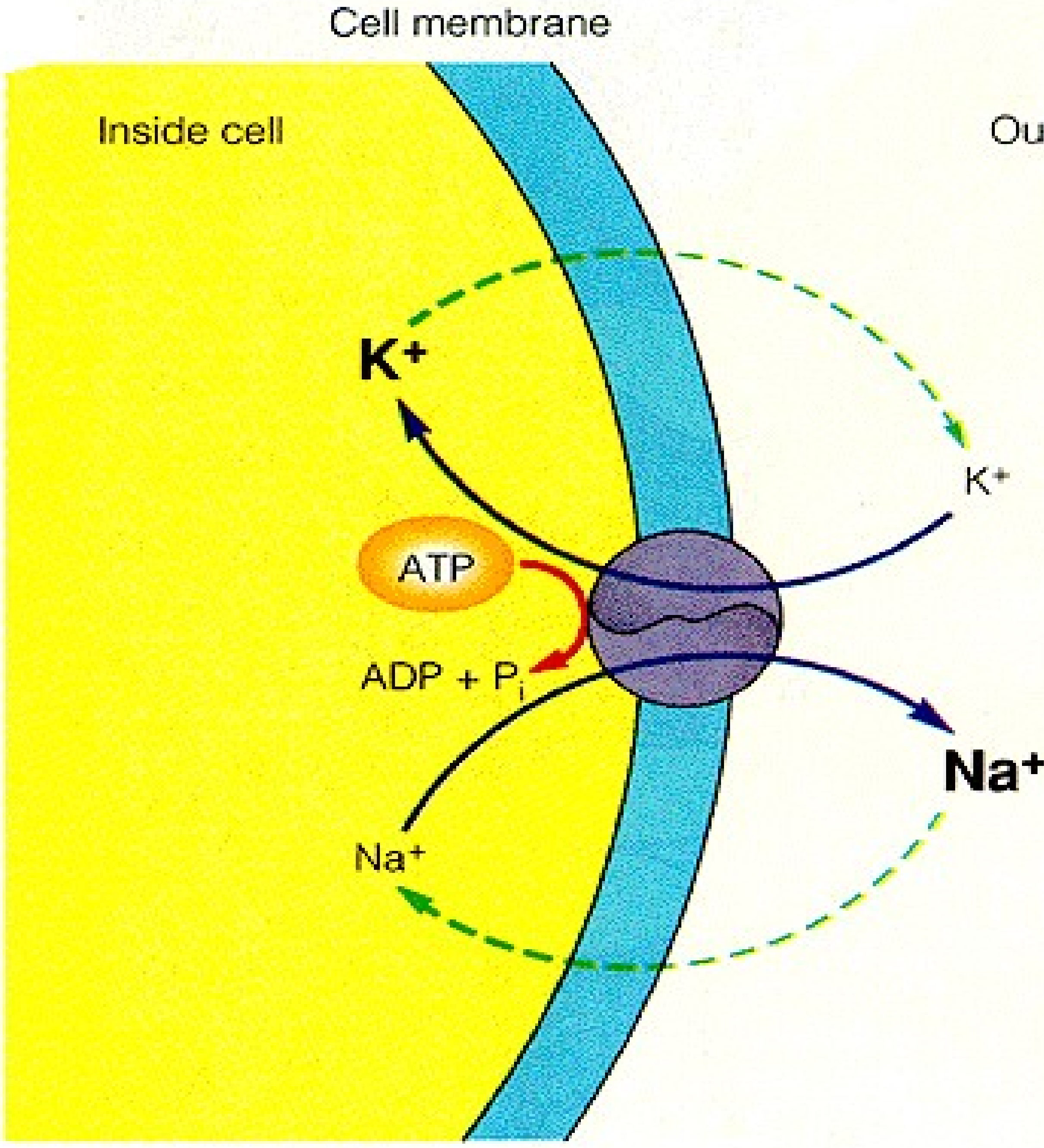
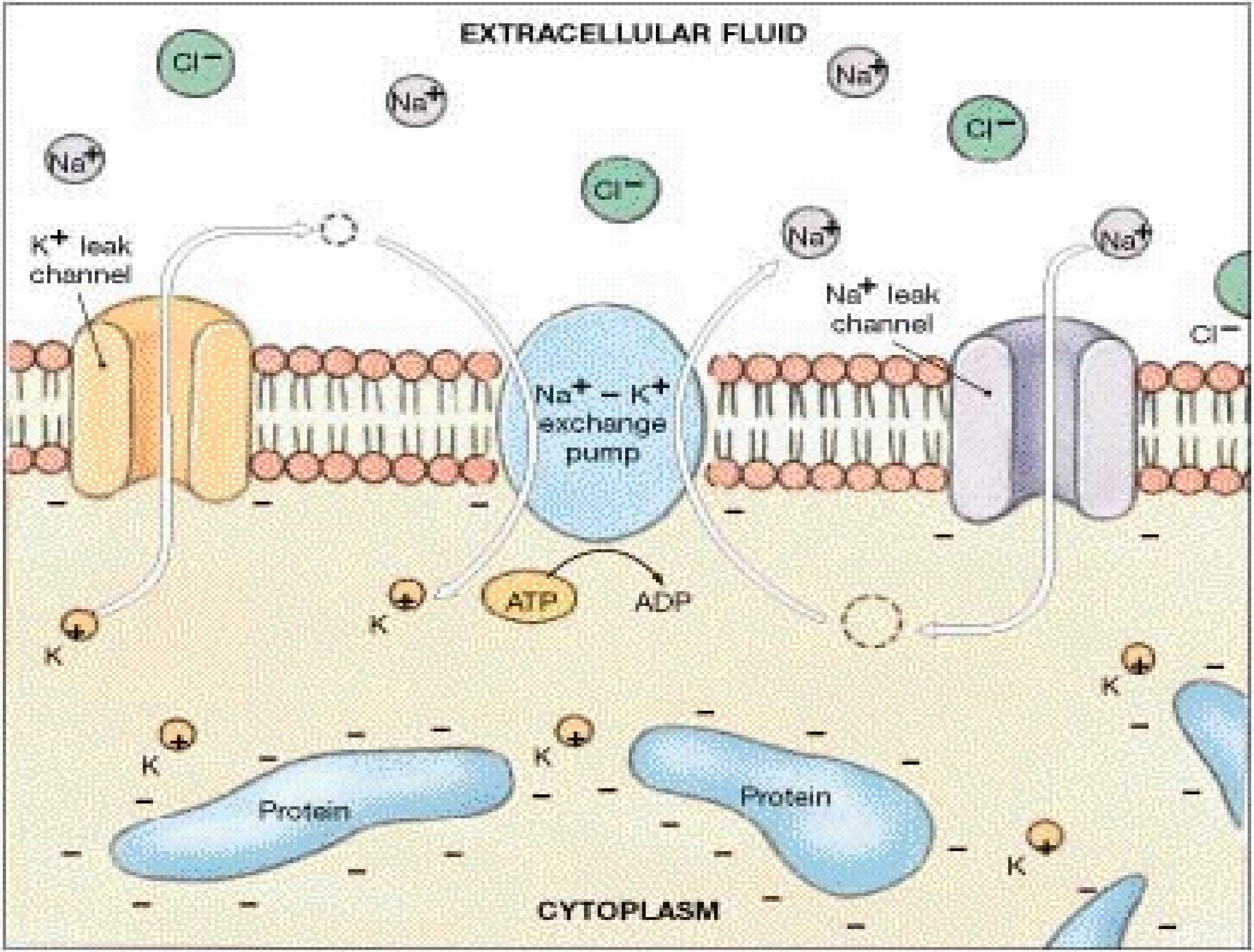
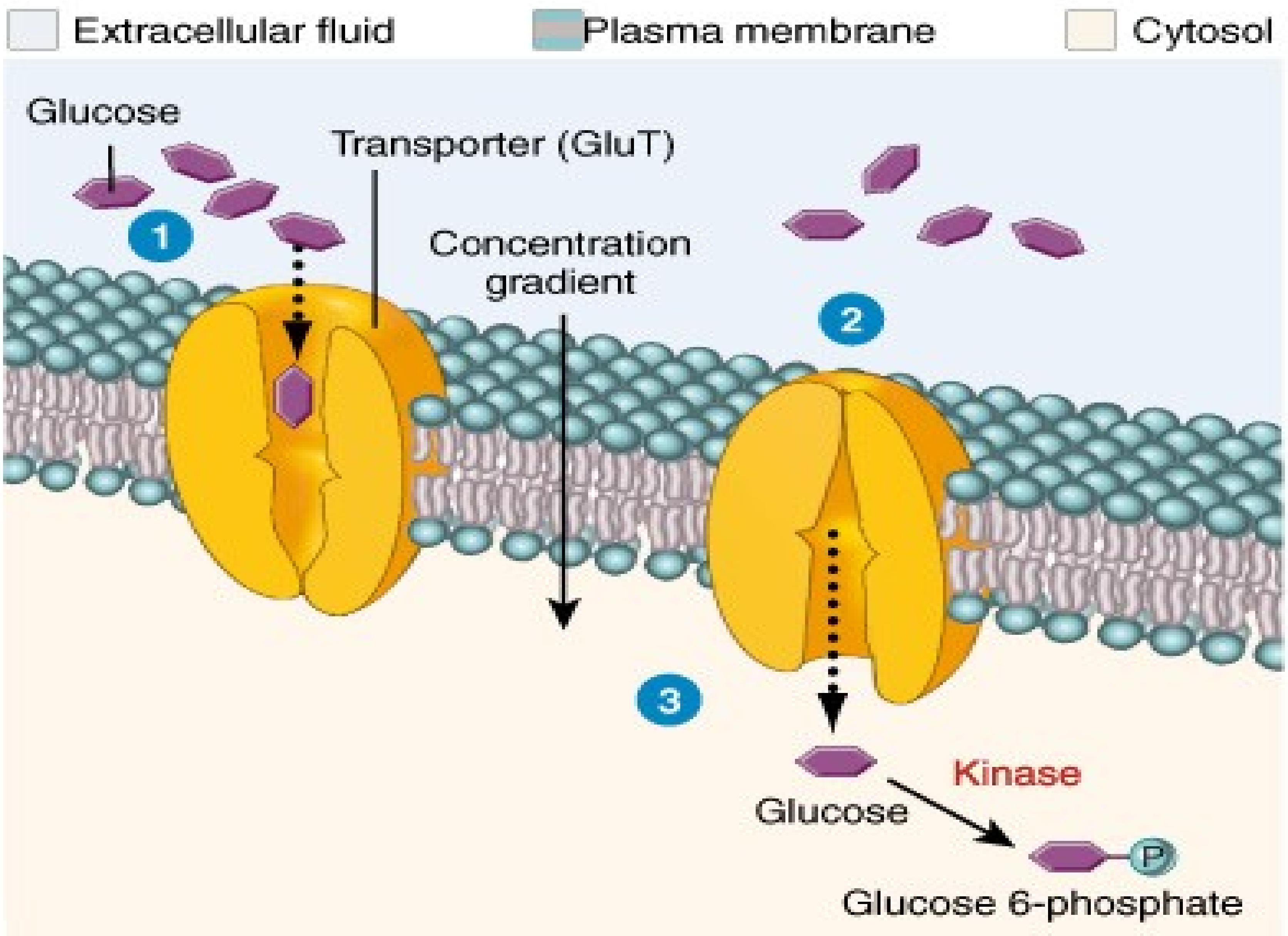
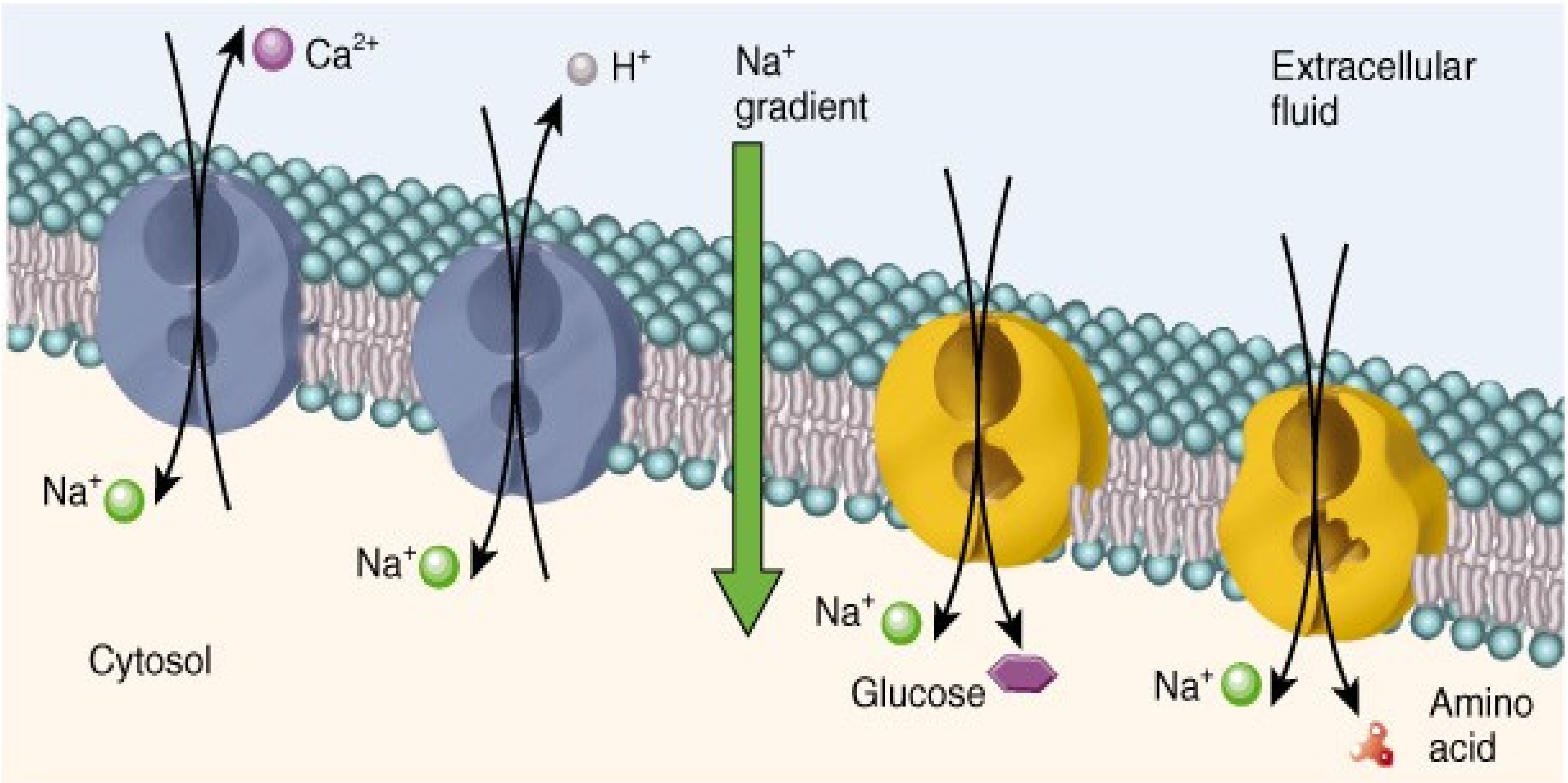


Figure 3
The Na+/K+ pump actively exchanges intracellular Na+ for K+.



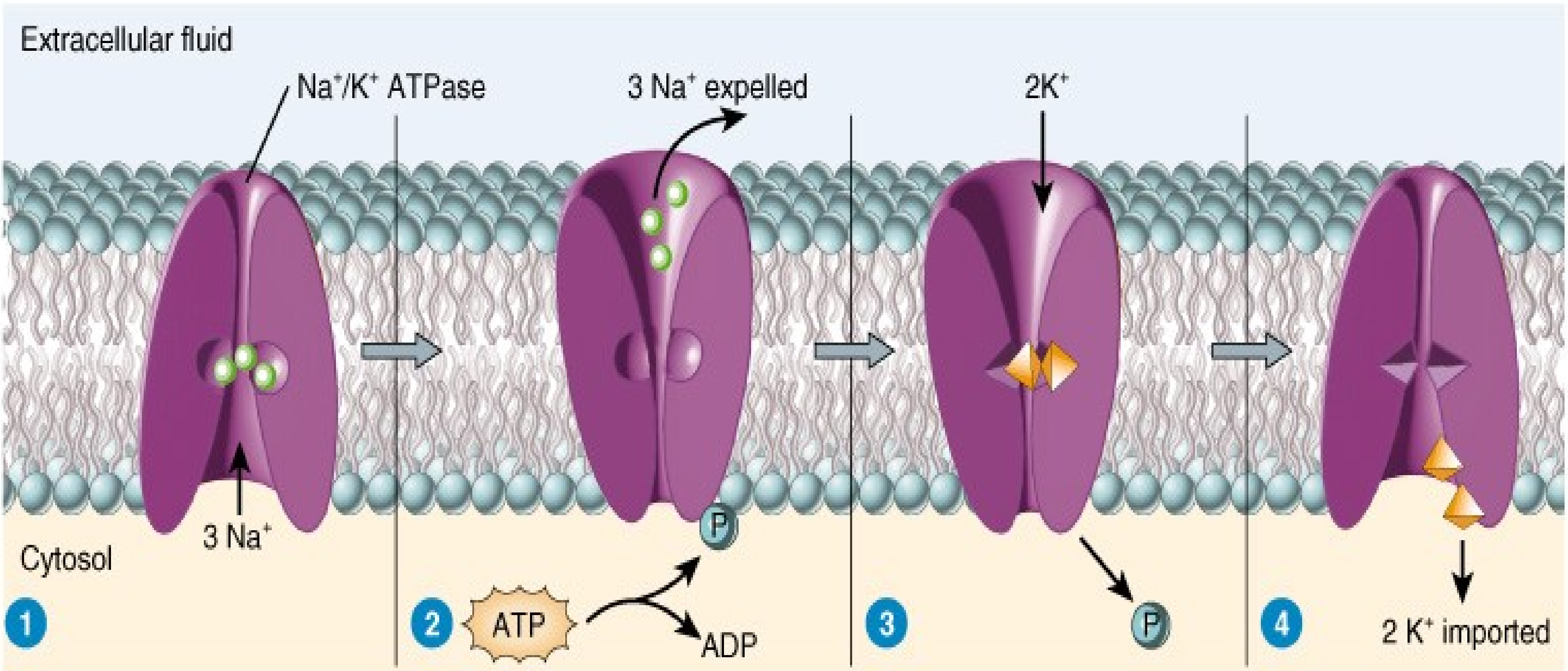
EXTRACELLULAR FLUID
Cl−
Na+
K+ leak channel
Na+ leak channel
Na+ – K+ exchange pump
ATP
ADP
K
Protein
Protein
CYTOPLASM


Extracellular fluid
Plasma membrane
Cytosol
Glucose
Transporter (GluT)
1
Concentration
gradient
2
3
Glucose
Kinase
P
Glucose 6-phosphate

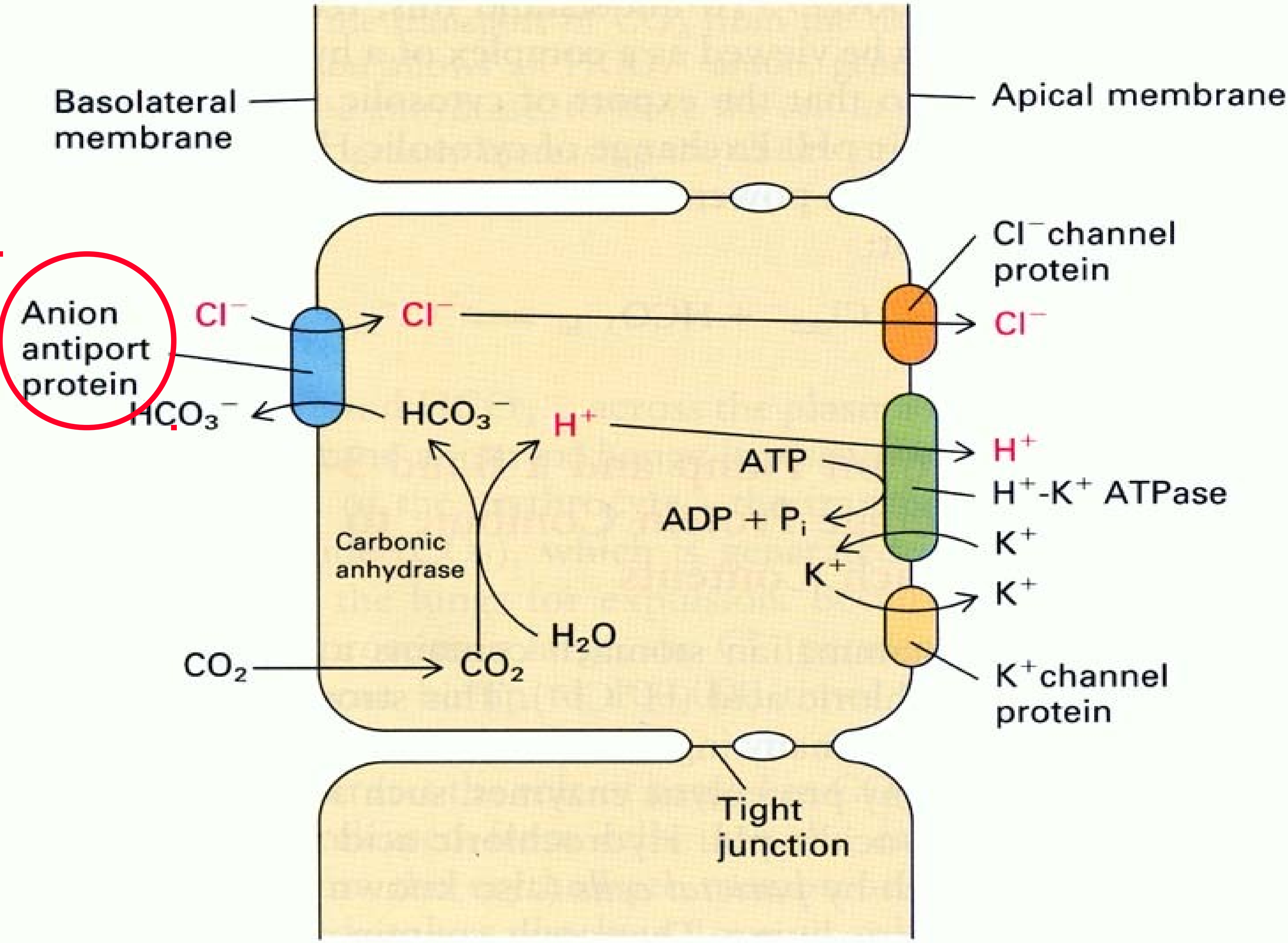


(a) Antiporters

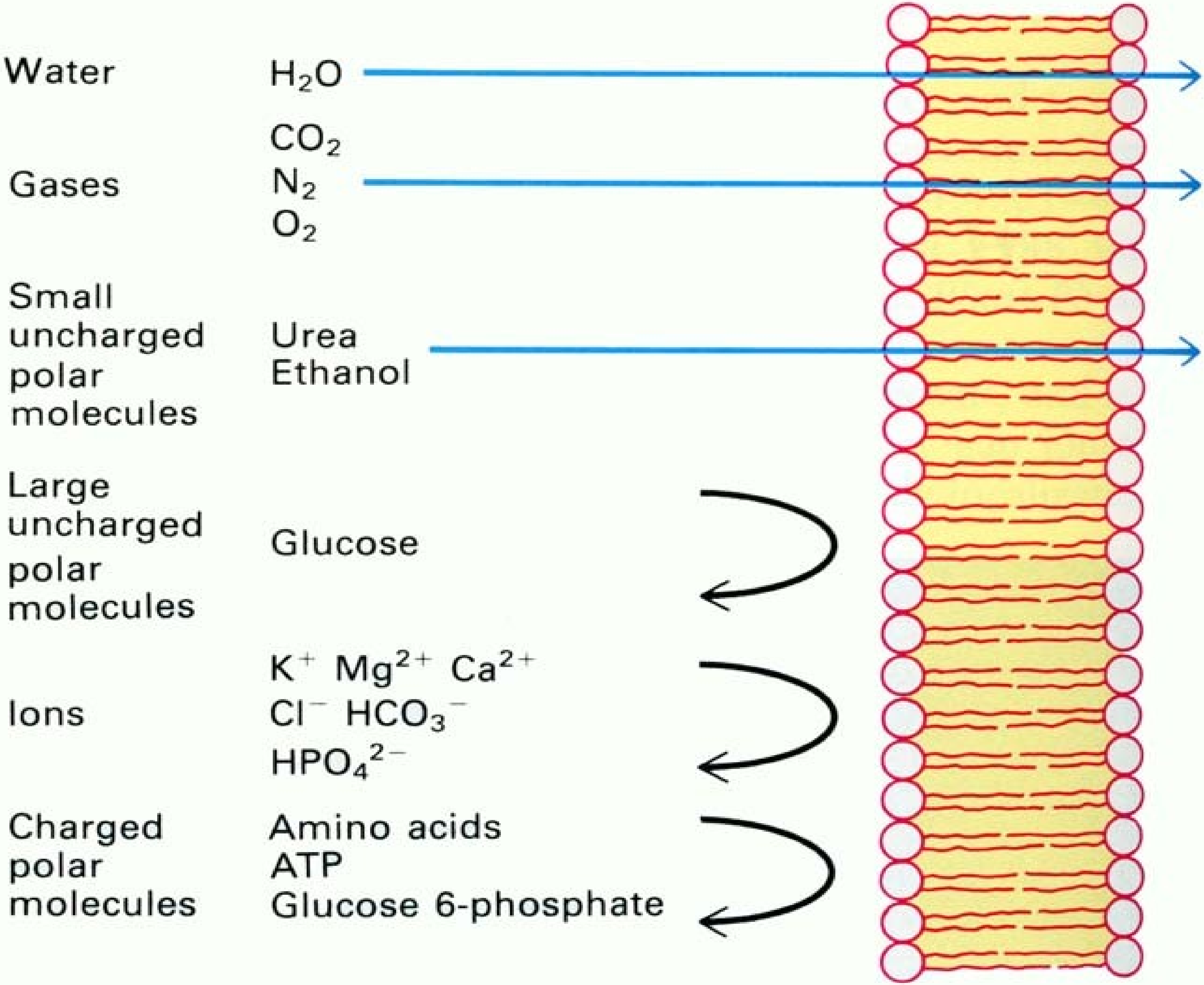
(b) Symporters



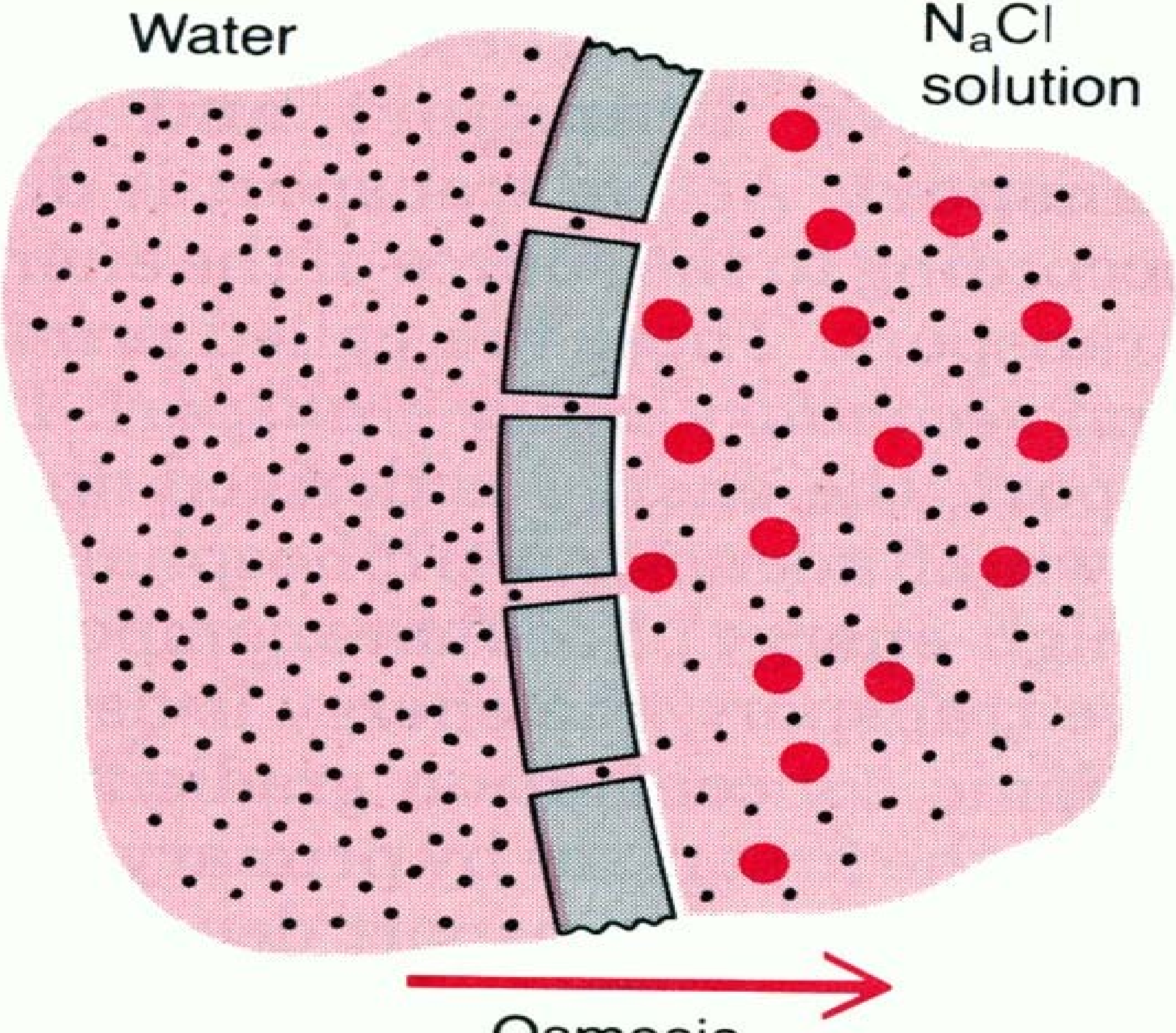
Extracellular fluid
Na⁺/K⁺ ATPase
3 Na⁺ expelled
2K⁺
3 Na⁺
Cytosol
P
ATP
ADP
P
2 K⁺ imported
1
2
3
4

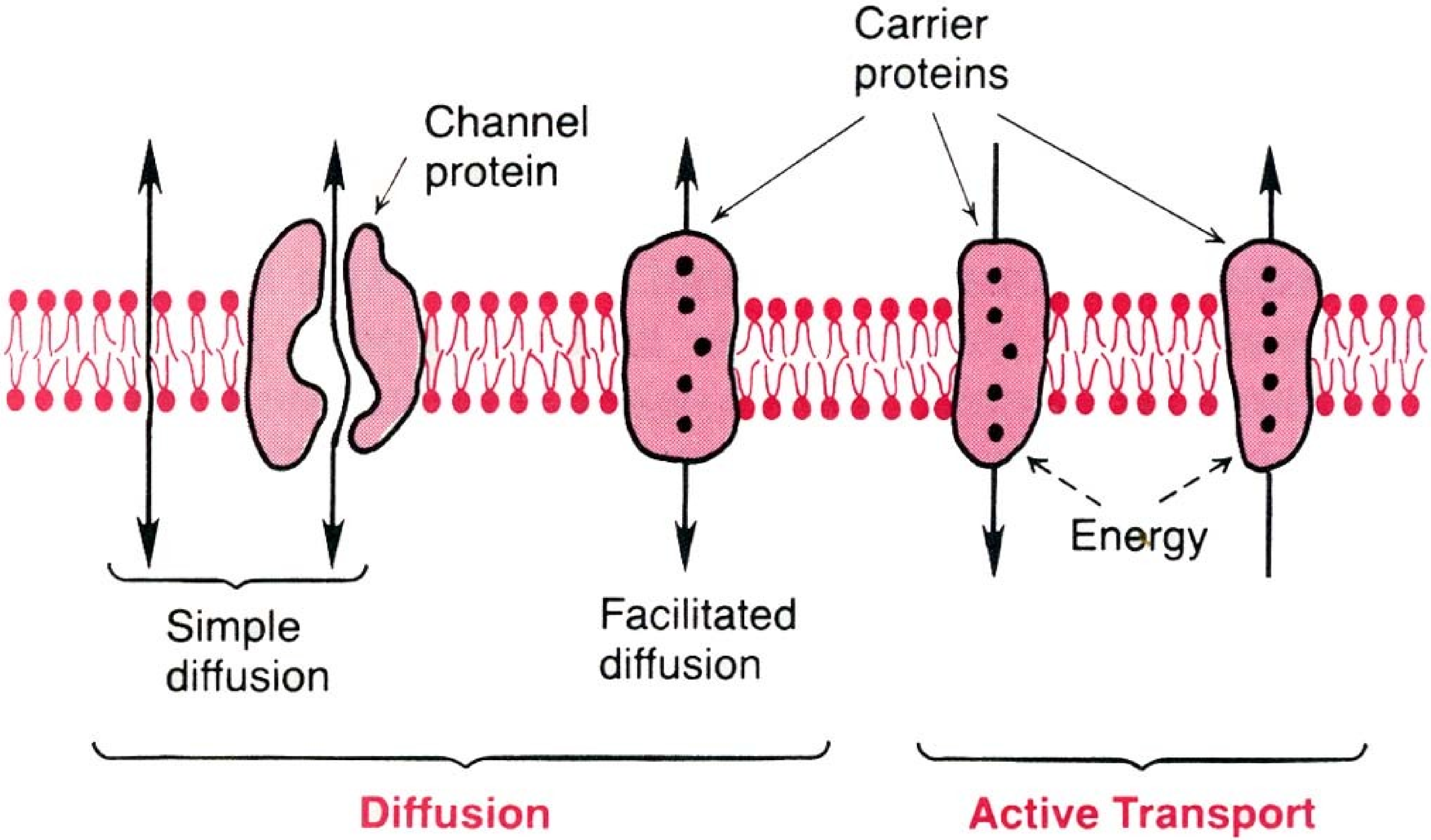


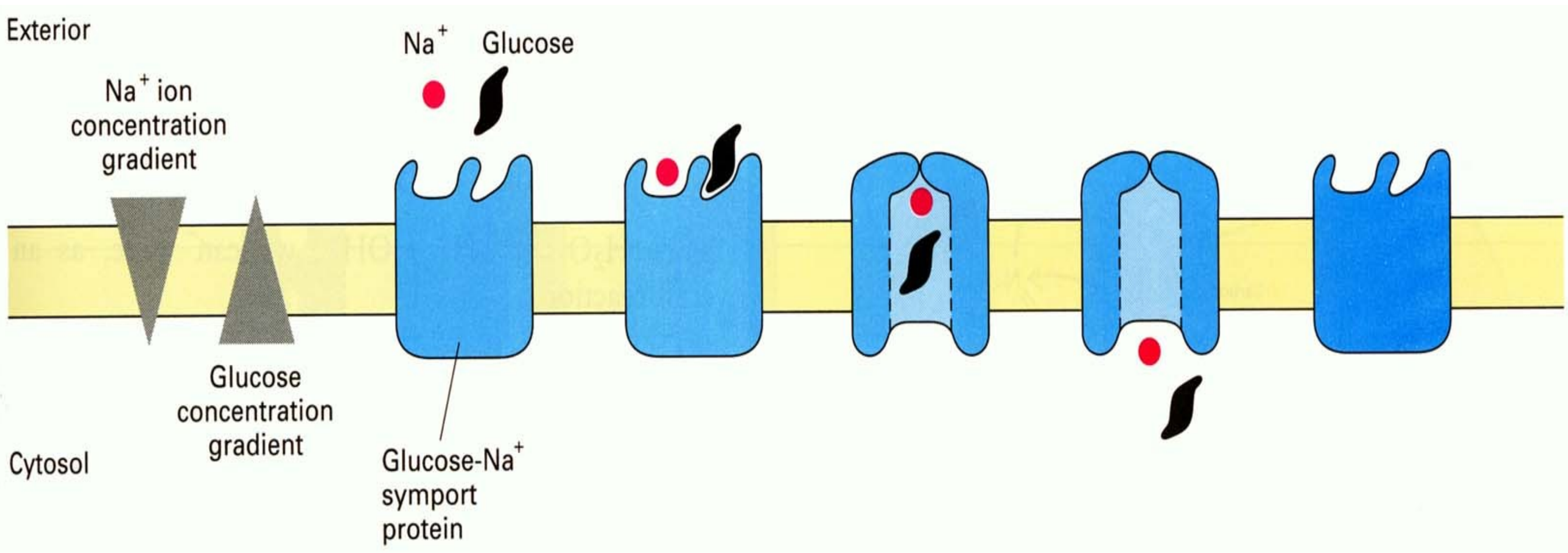
Basolateral membrane
Apical membrane
Cl⁻ channel protein
Anion antiport protein
Cl⁻
Cl⁻
Cl⁻
HCO₃⁻
HCO₃⁻
H⁺
H⁺
ATP
ADP + Pᵢ
H⁺-K⁺ ATPase
K⁺
K⁺
K⁺
Carbonic anhydrase
H₂O
CO₂
CO₂
K⁺ channel protein
Tight junction

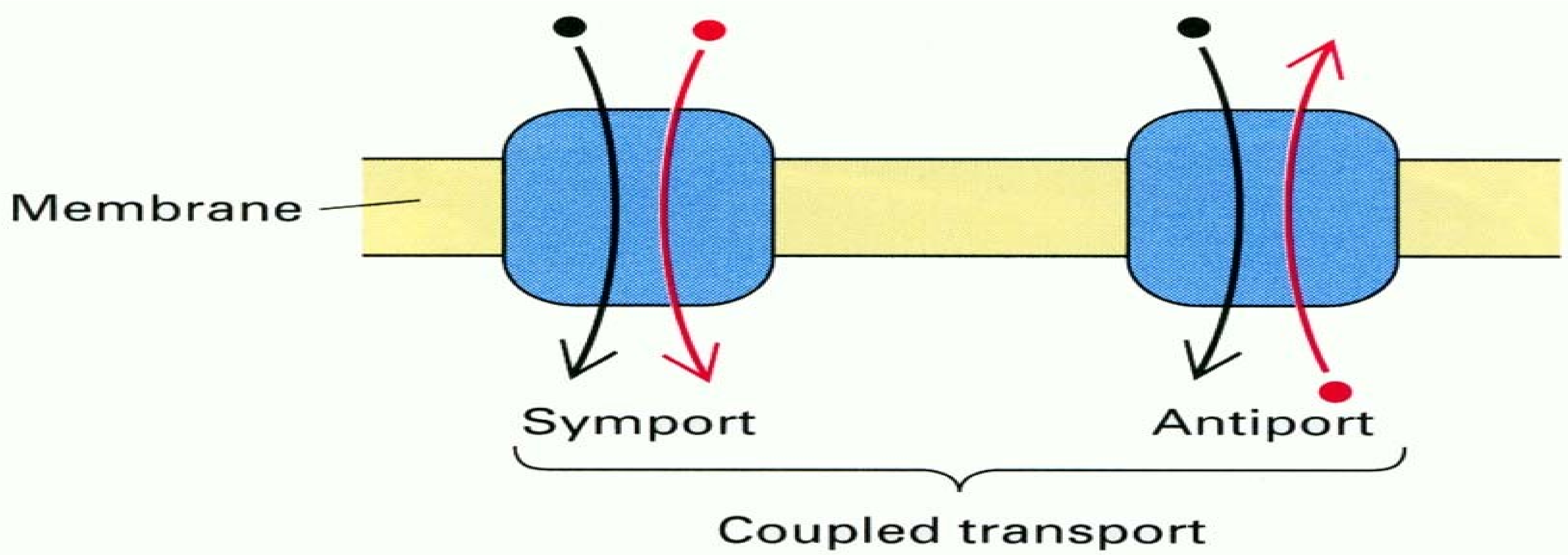


Water
H_2O
Gases
CO_2
N_2
O_2
Small uncharged polar molecules
Urea
Ethanol
Large uncharged polar molecules
Glucose
Ions
K^+ Mg^{2+} Ca^{2+}
Cl^- HCO_3^-
HPO_4^{2-}
Charged polar molecules
Amino acids
ATP
Glucose 6-phosphate


Water
NaCl
solution
Osmosis


Carrier
proteins
Channel
protein
Energy
Simple
diffusion
Facilitated
diffusion
Diffusion
Active Transport


Exterior
Na+ ion concentration gradient
Na+
Glucose
Glucose concentration gradient
Cytosol
Glucose-Na+ symport protein

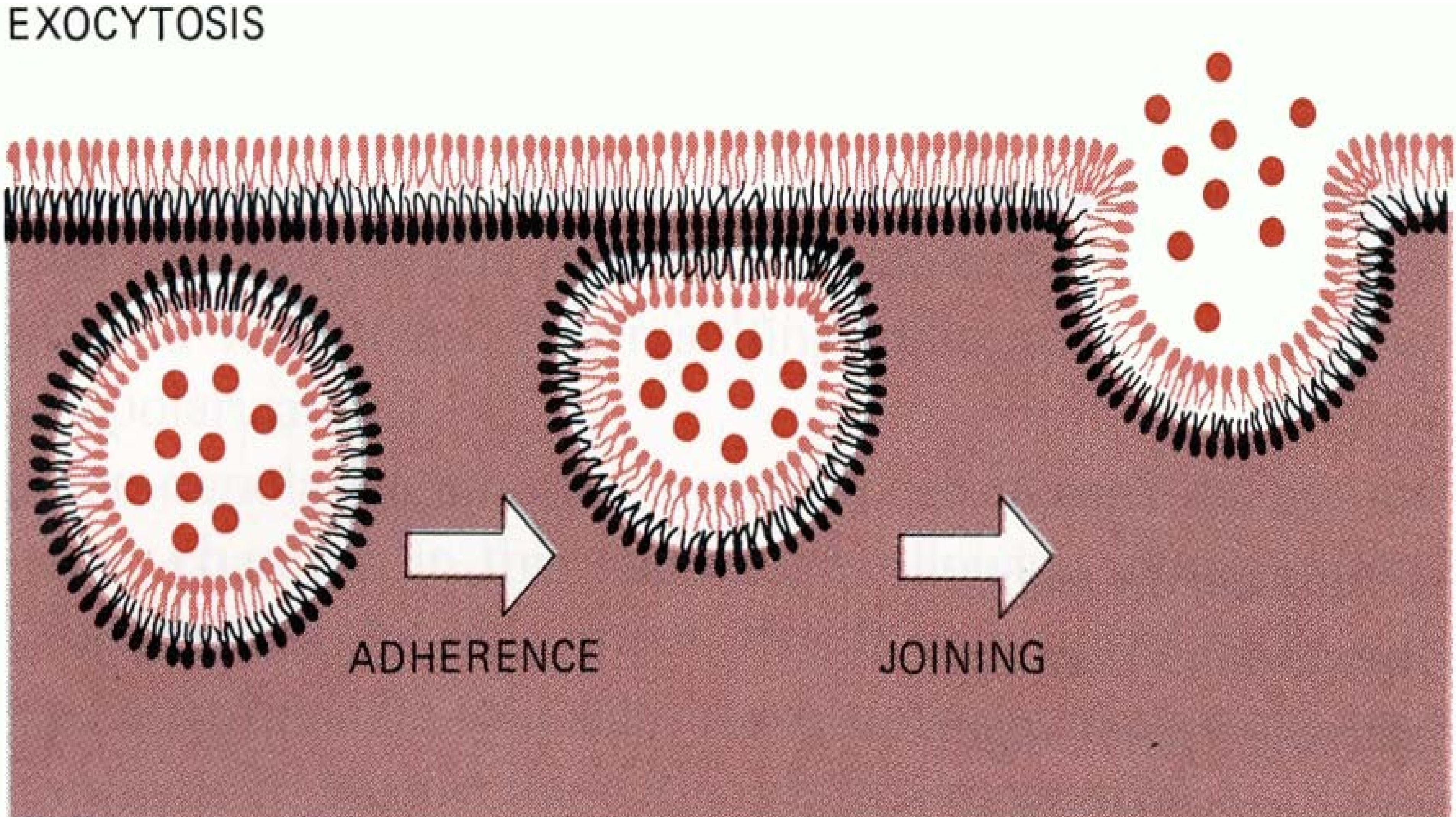

Membrane
Symport
Antiport
Coupled transport

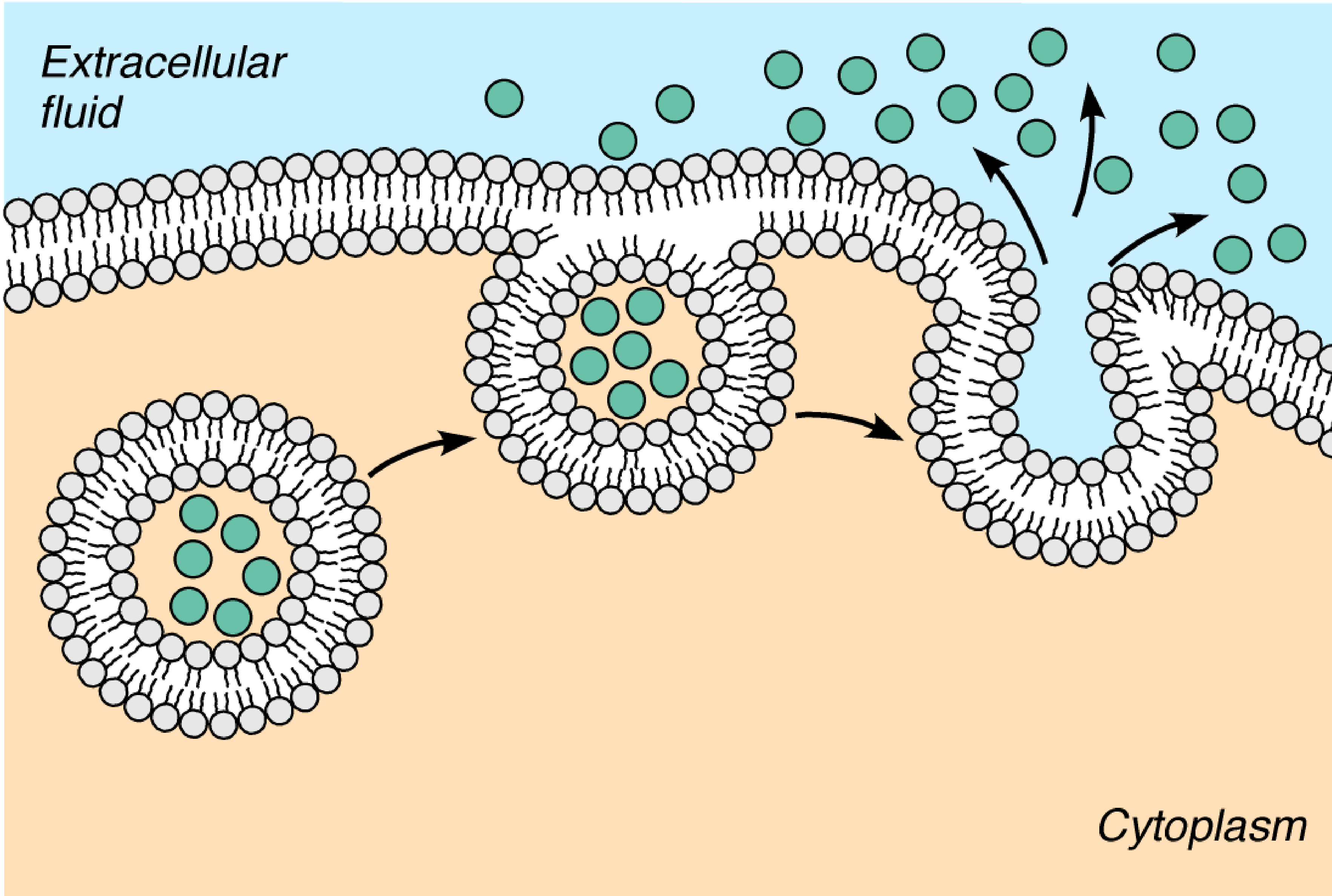
Vesicular Transport

- A vesicle is a small membranous sac formed by budding off from an existing membrane.
- Two types of vesicular transport are endocytosis and exocytosis.

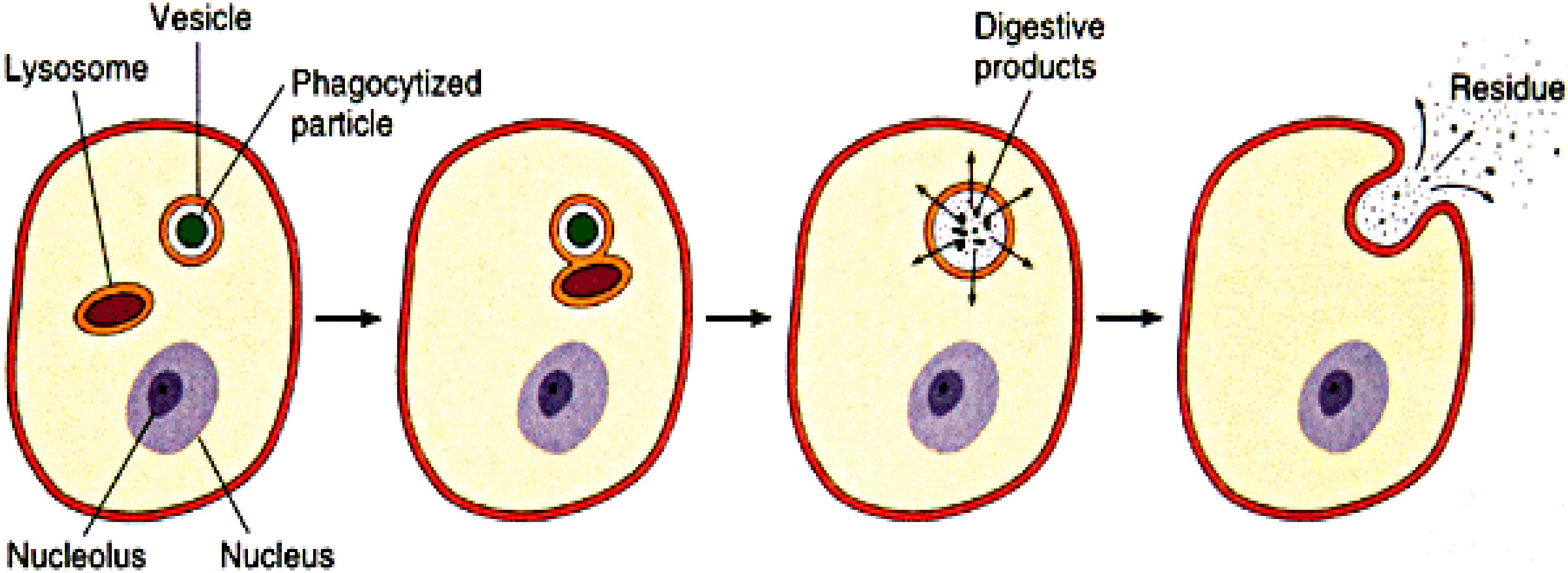
Vesicular Transport

- In **exocytosis**, membrane-enclosed structures called secretory vesicles that form inside the cell fuse with the plasma membrane and release their contents into the extracellular fluid (Figs. 3.13 through 3.15).


EXOCYTOSIS
ADHERENCE
JOINING

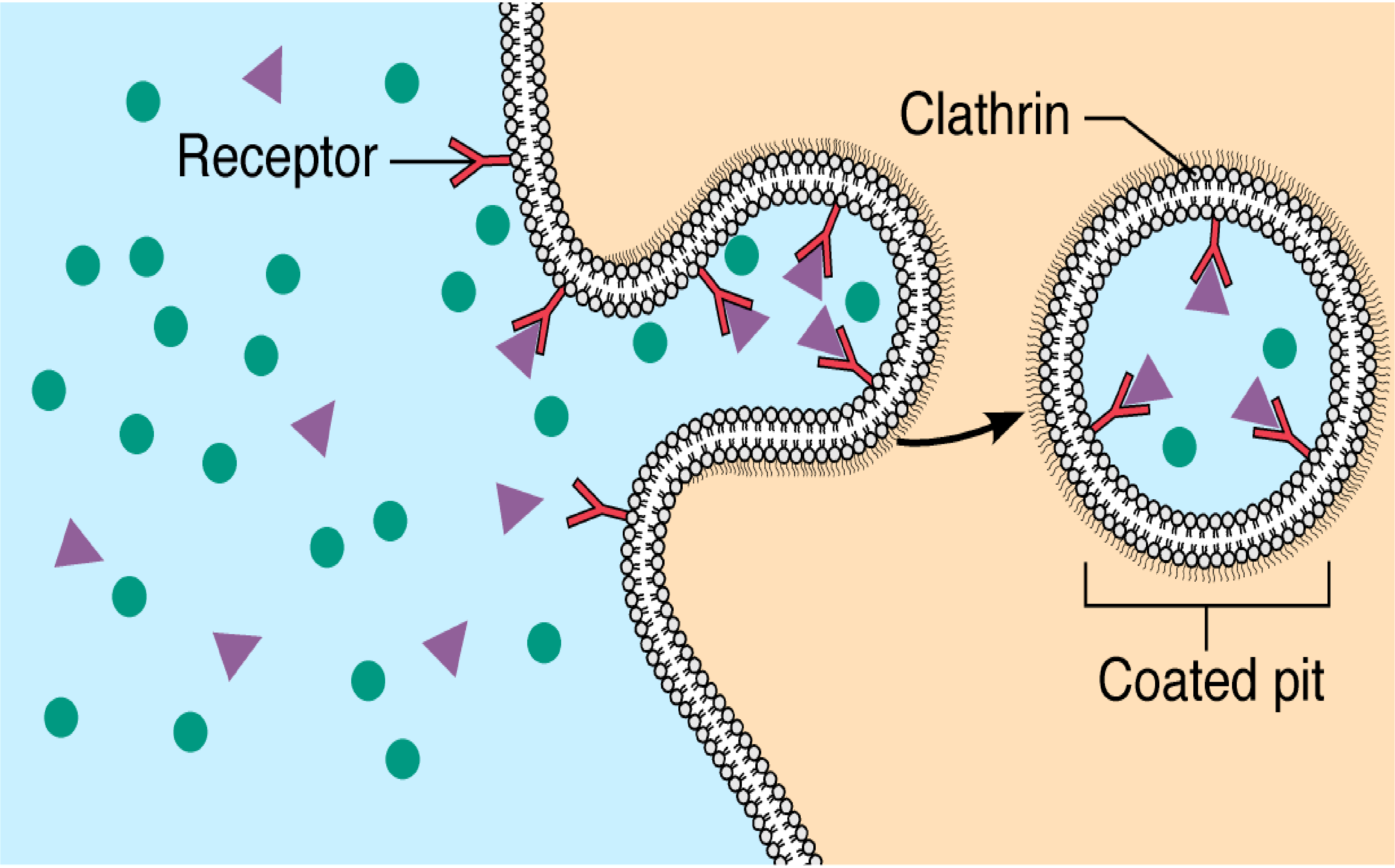

Extracellular fluid
Cytoplasm

Exocytosis.

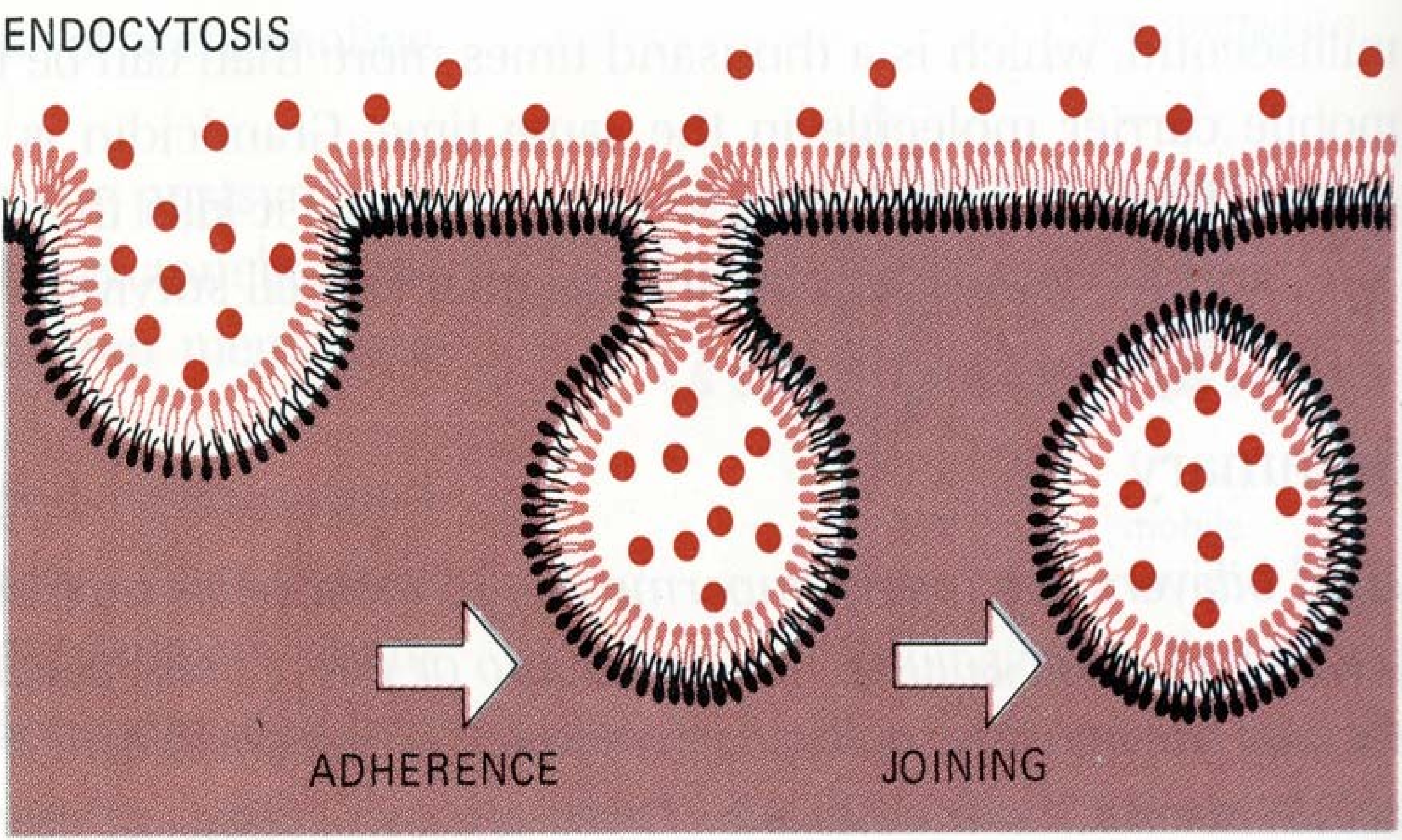

Vesicle
Lysosome
Phagocytized particle
Digestive products
Residue
Nucleolus
Nucleus

Vesicular Transport

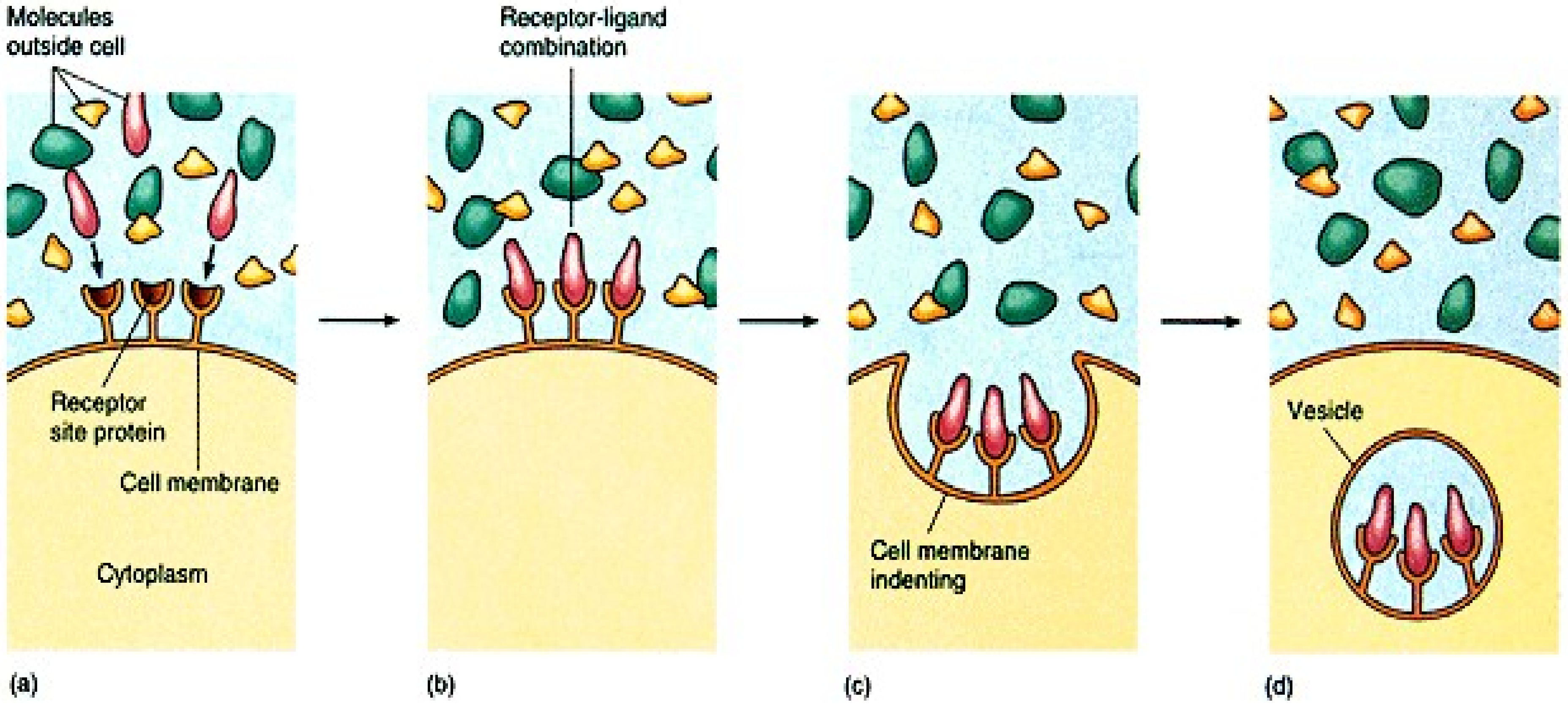
- **Endocytosis -** materials move into a cell in a vesicle formed from the plasma membrane.
  - *Receptor-mediated endocytosis* is the selective uptake of large molecules and particles by cells (Fig 3.13).
  - The steps of receptor-mediated endocytosis includes binding, vesicle formation, uncoating, fusion and endosome formation, recycling of receptors, degradation in lysosomes, and transcytosis.



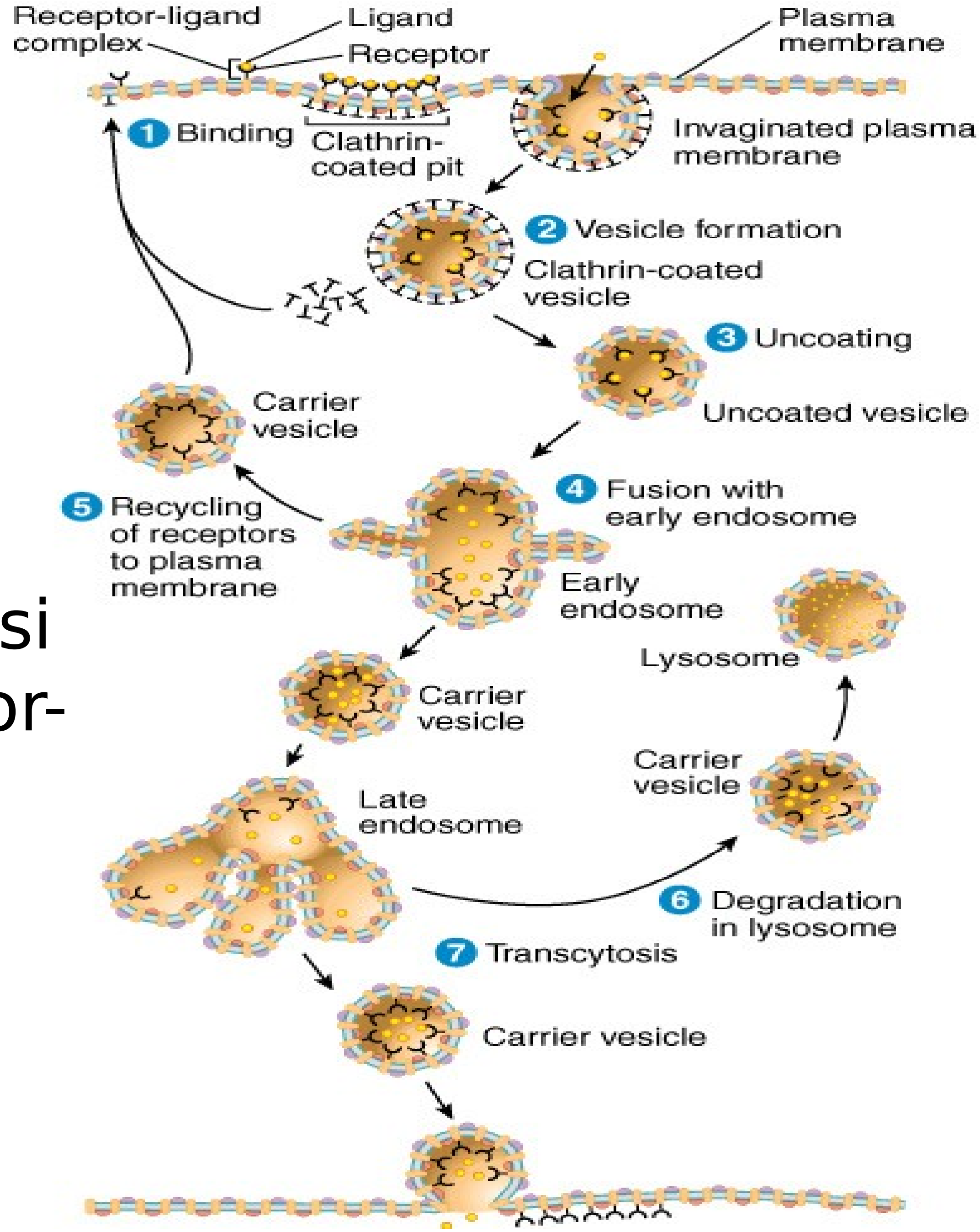
(c) Receptor-mediated endocytosis

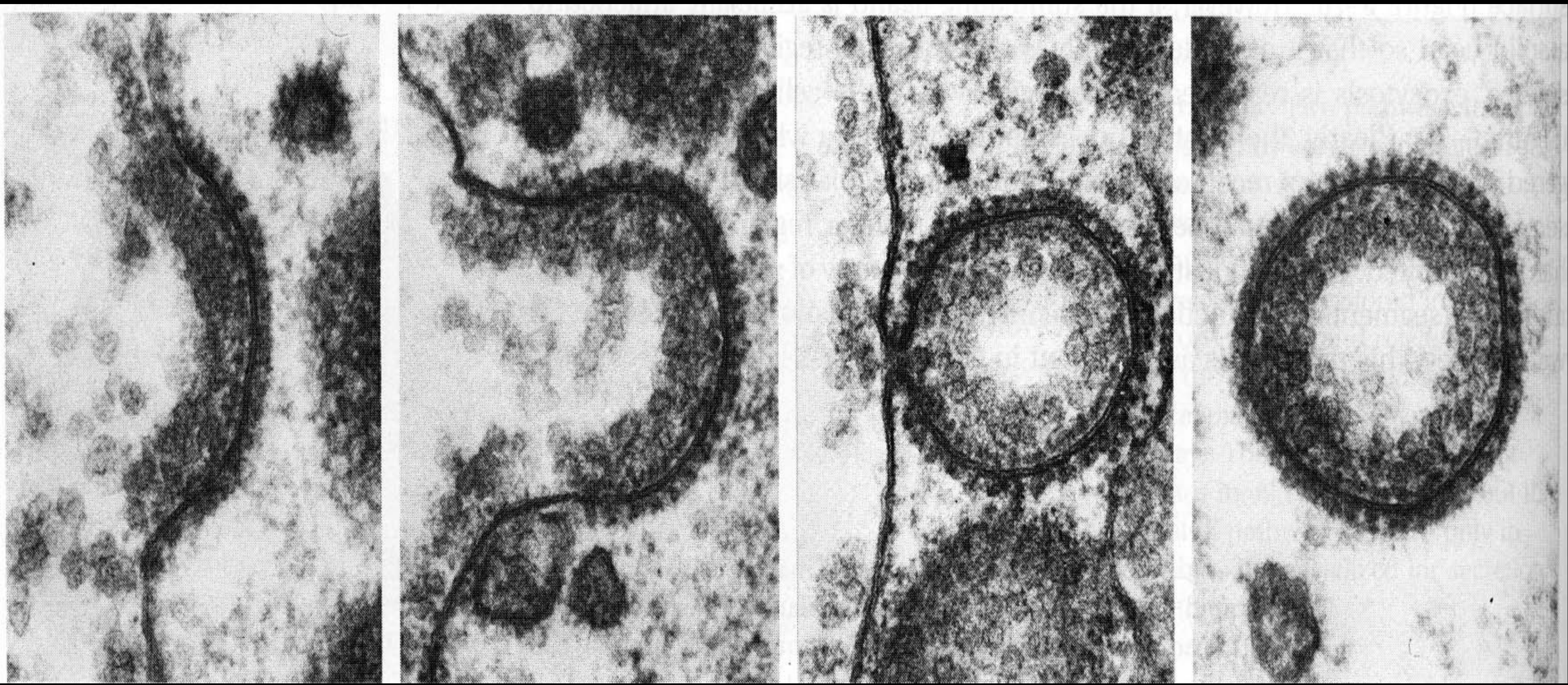

ENDOCYTOSIS
ADHERENCE
JOINING

Endocytosis.



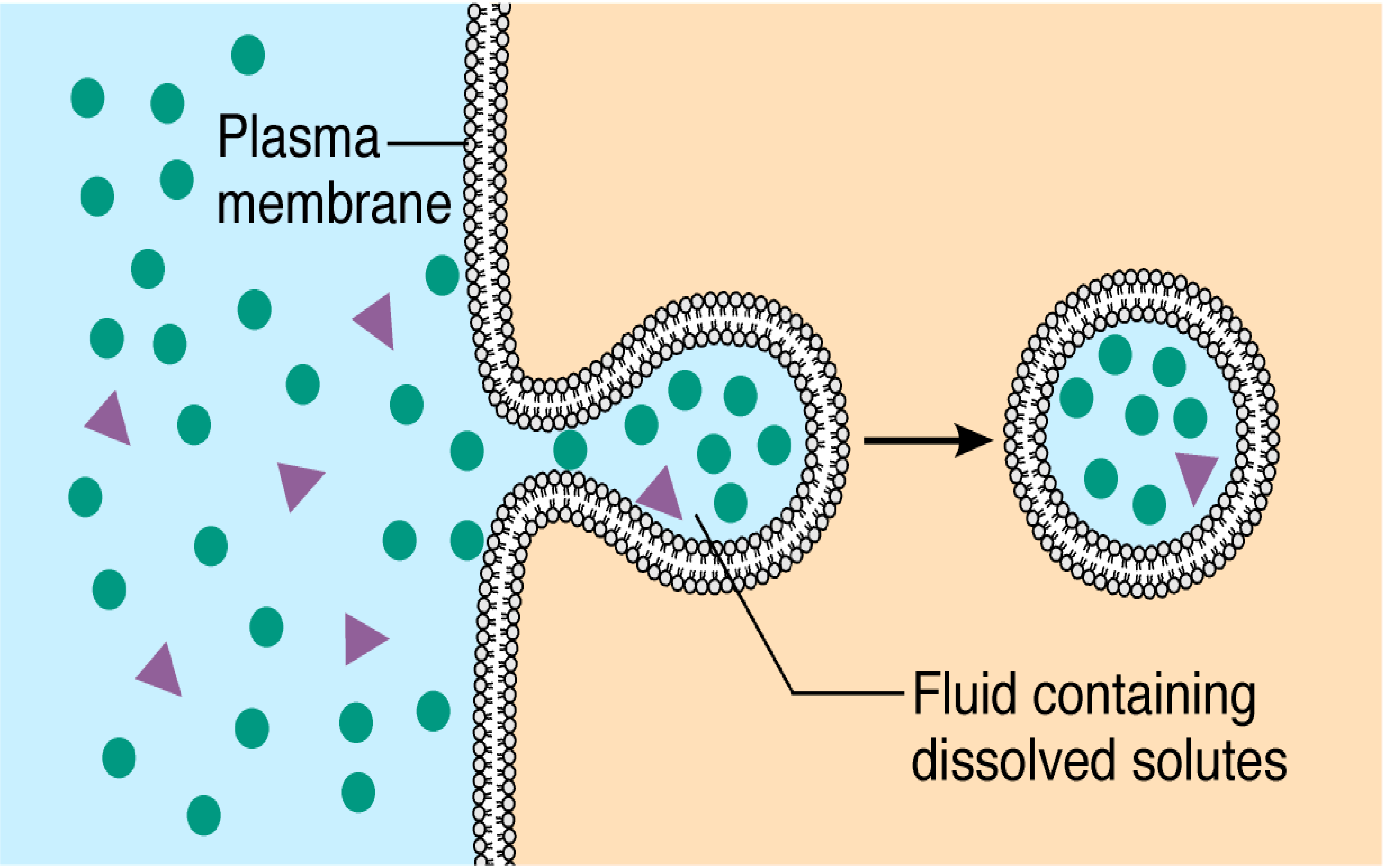
Endocytosis: receptor-mediated





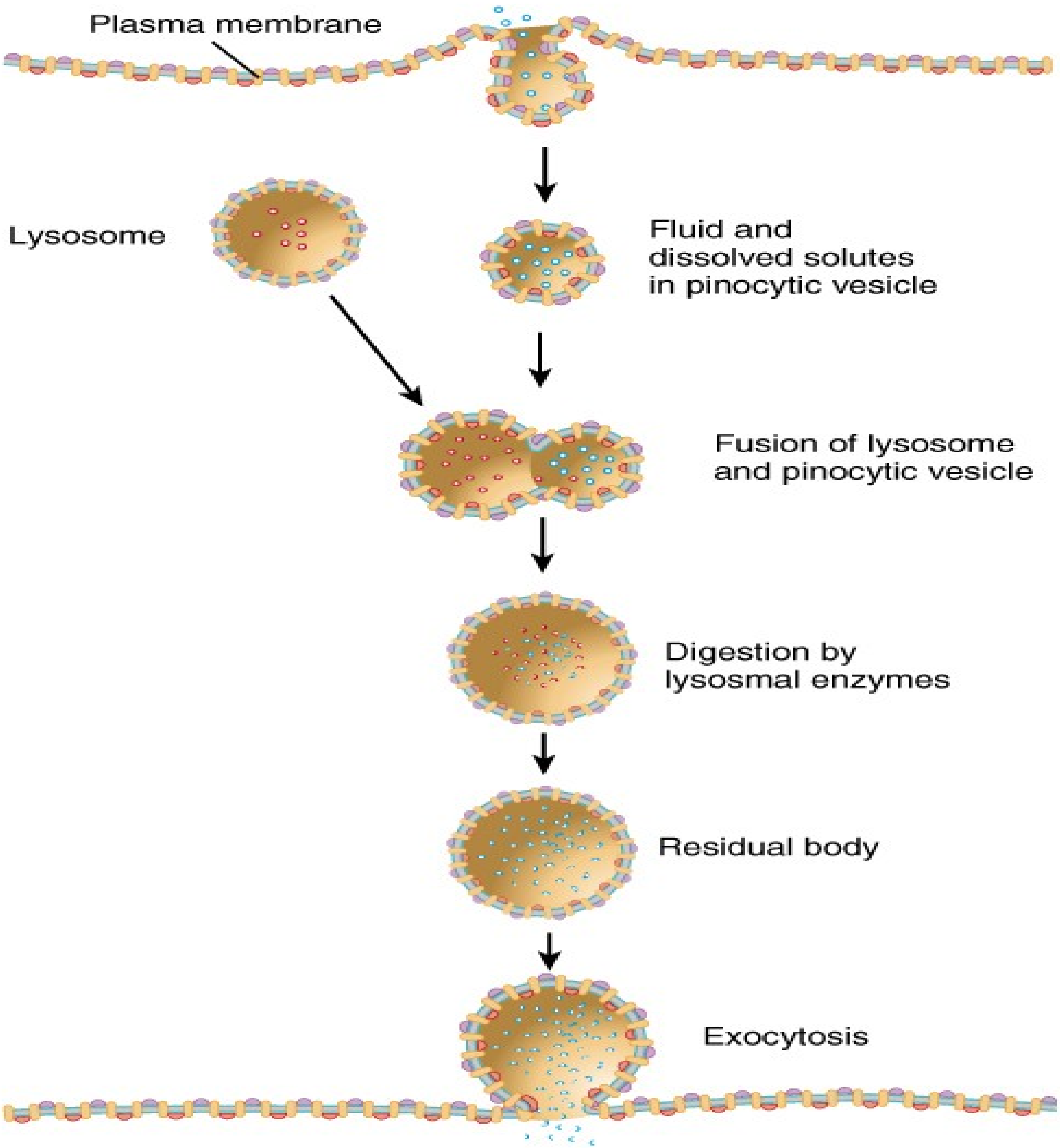
Vesicular Transport

- **Endocytosis**
  - Viruses can take advantage of this mechanism to enter cells.
  - *Phagocytosis* is the ingestion of solid particles (Fig. 3.14).
  - *Pinocytosis* is the ingestion of extracellular fluid (Fig. 3.15).

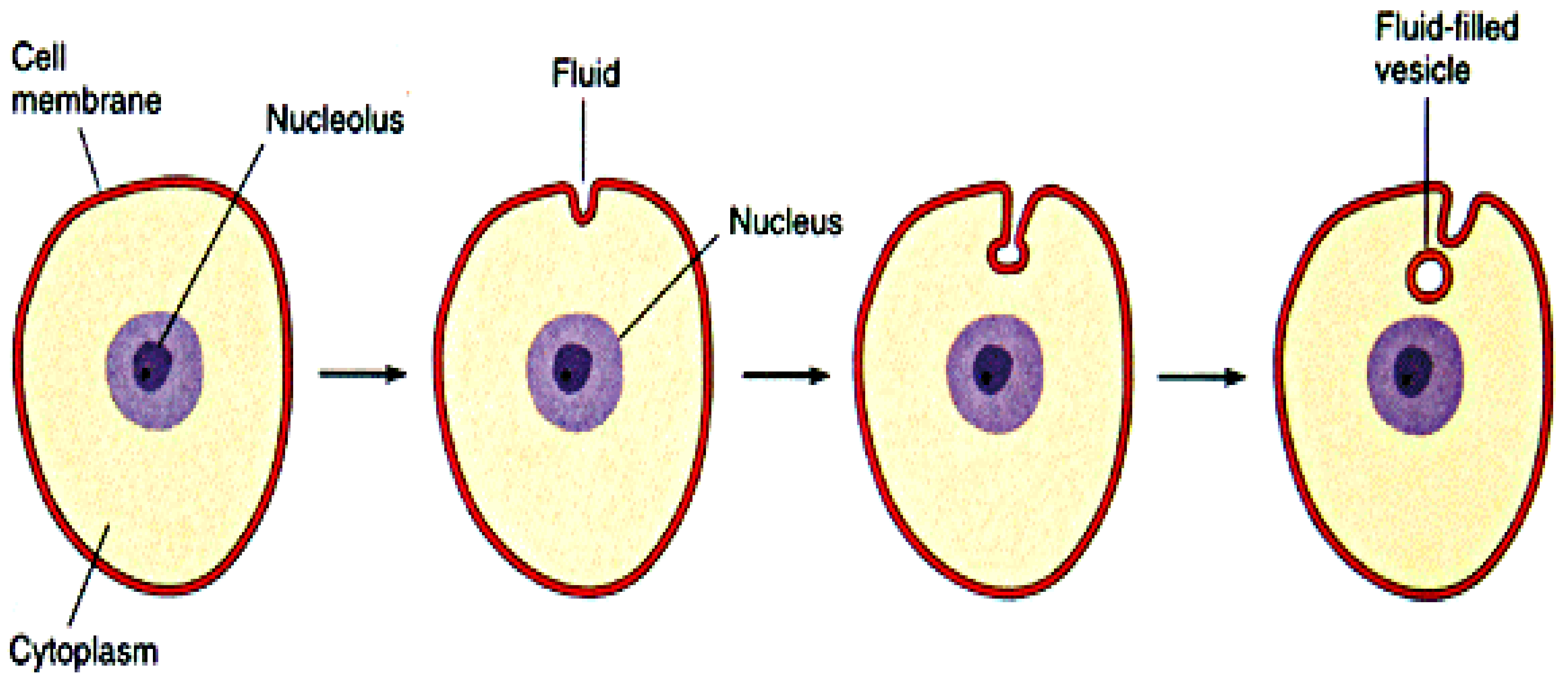


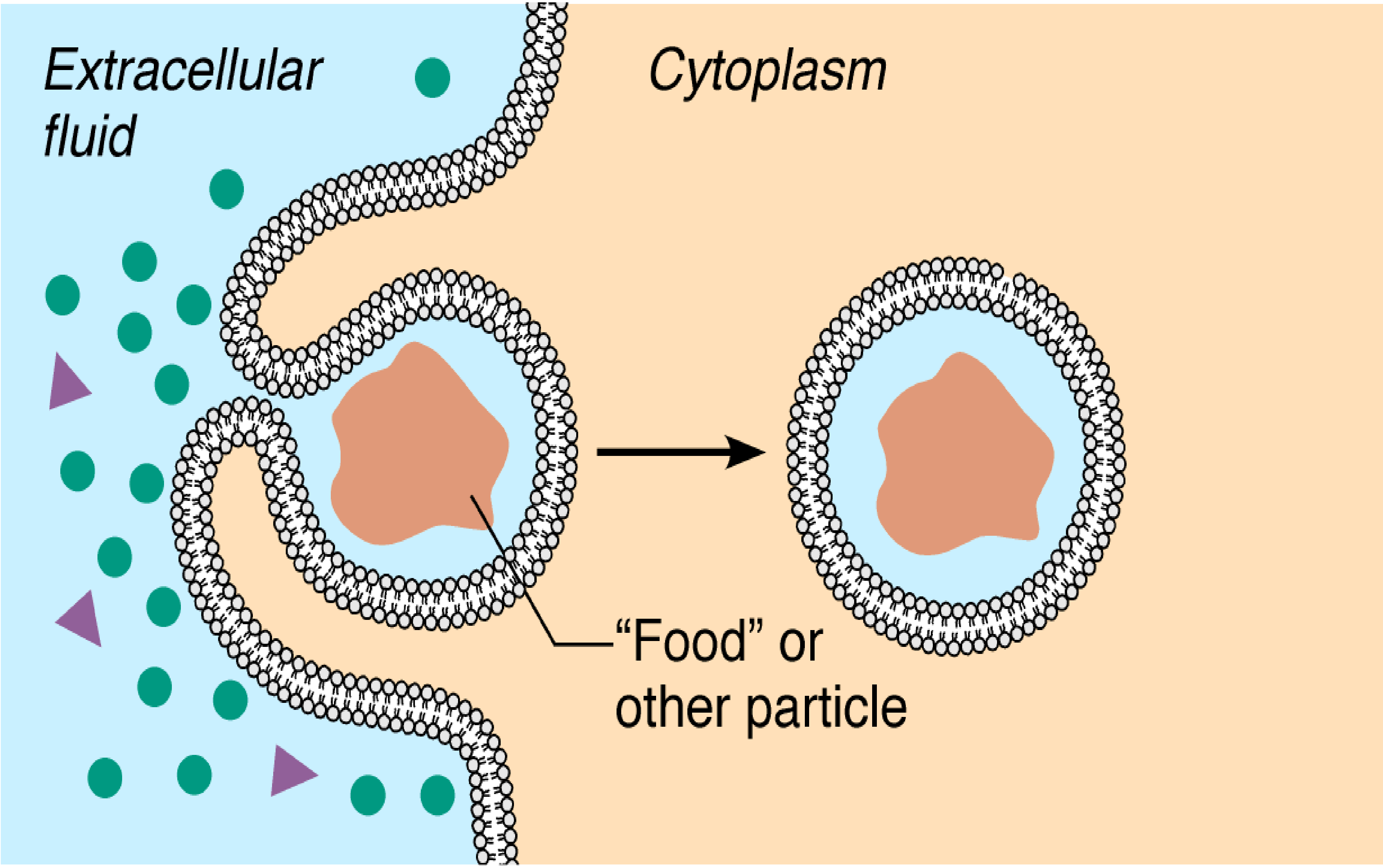
(b) Pinocytosis

Pinocytosis



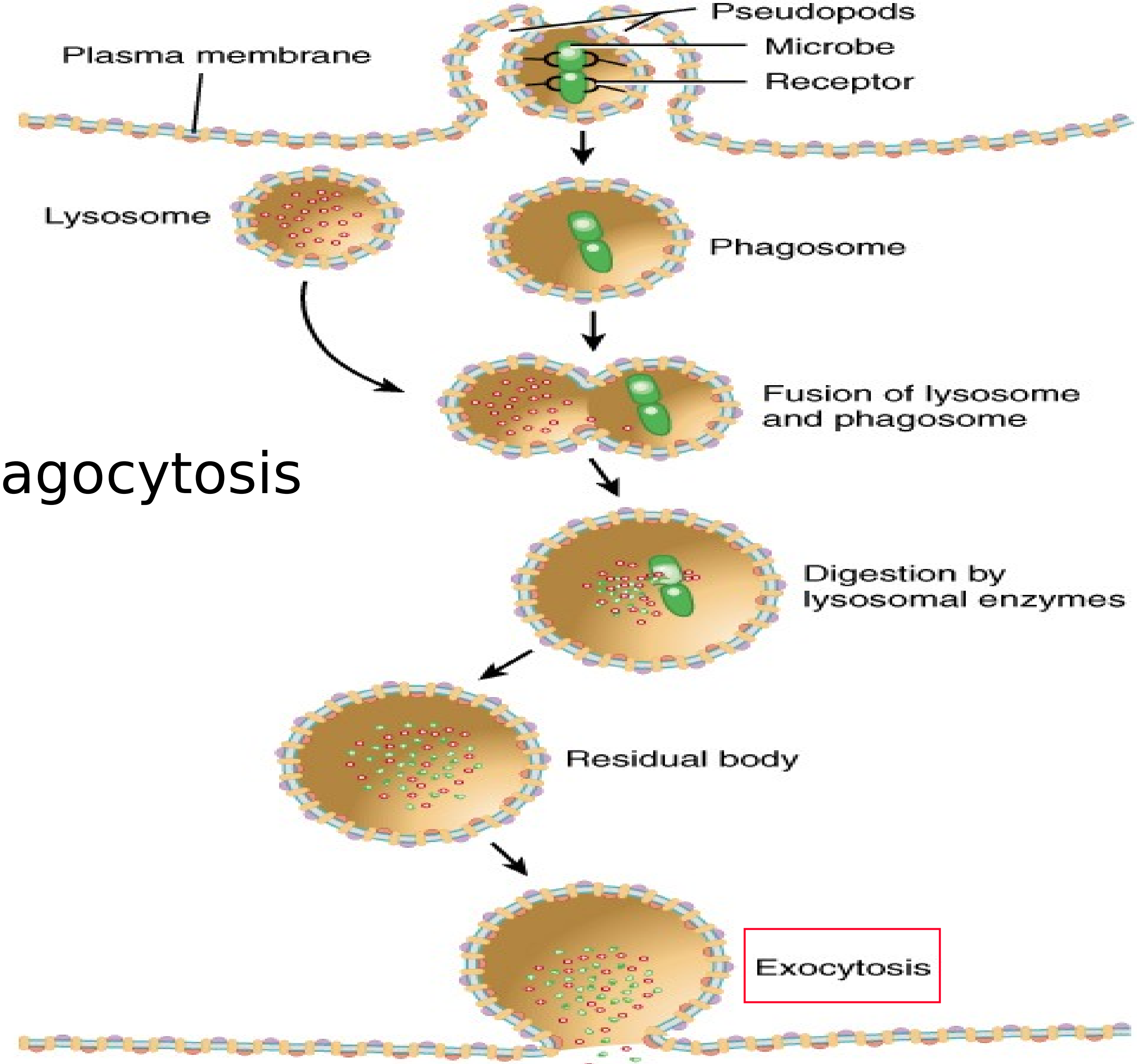
Pinocytosis.



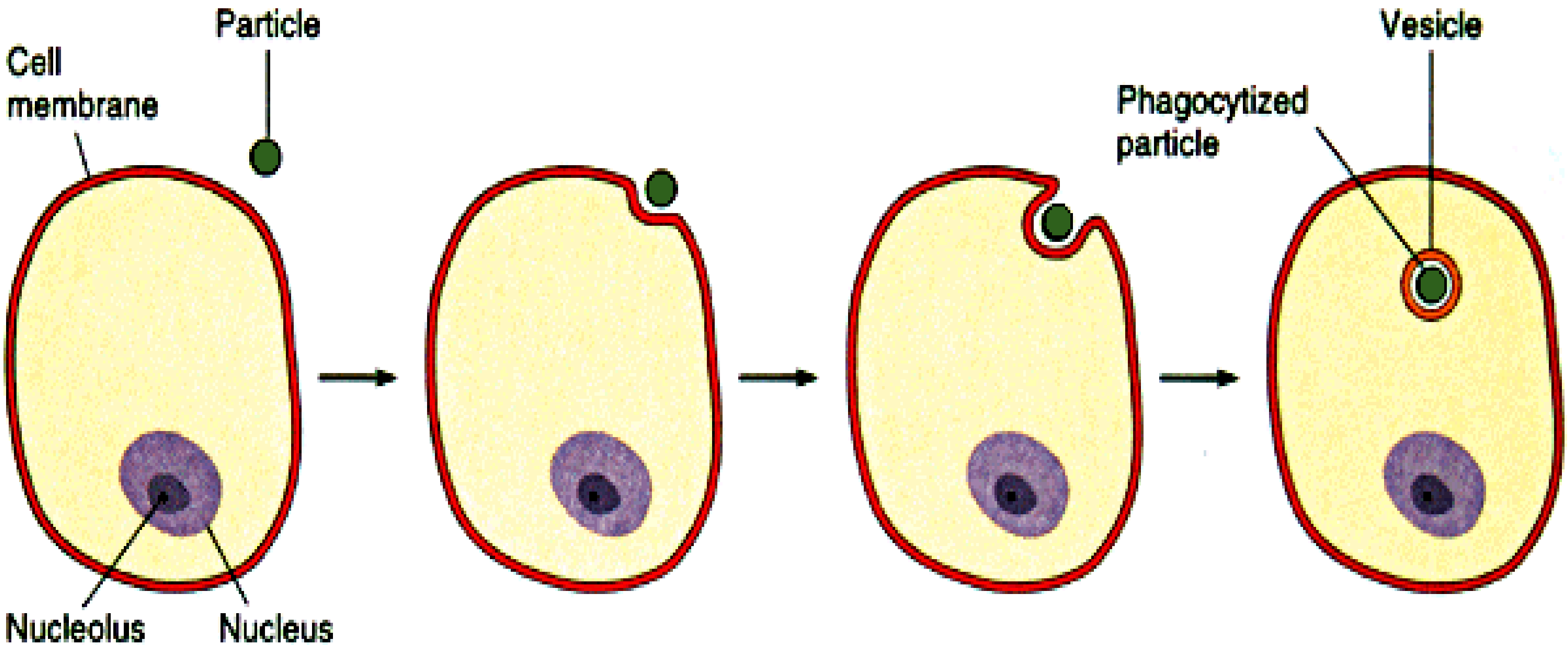


(a) Phagocytosis

Phagocytosis



Phagocytosis



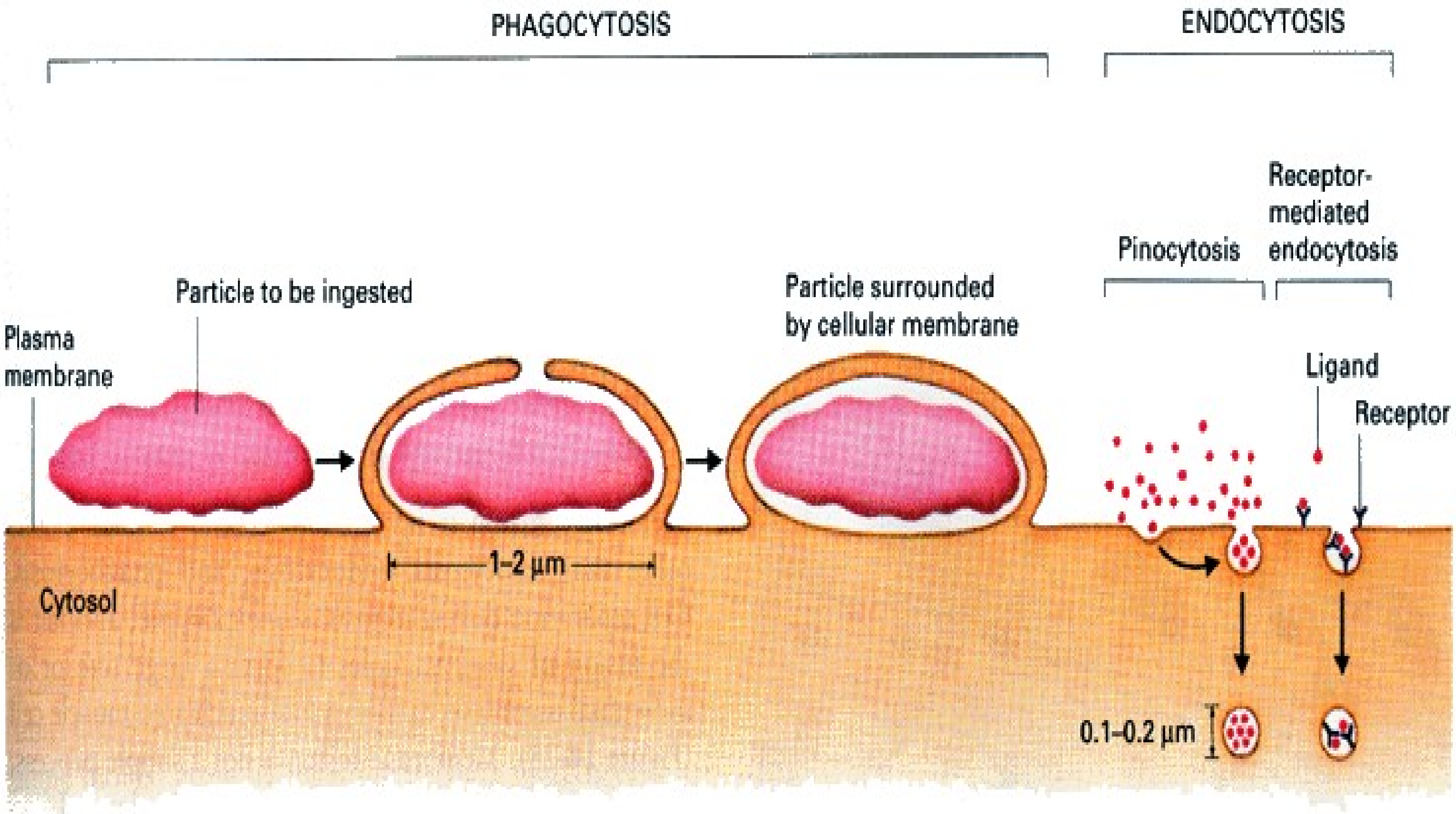
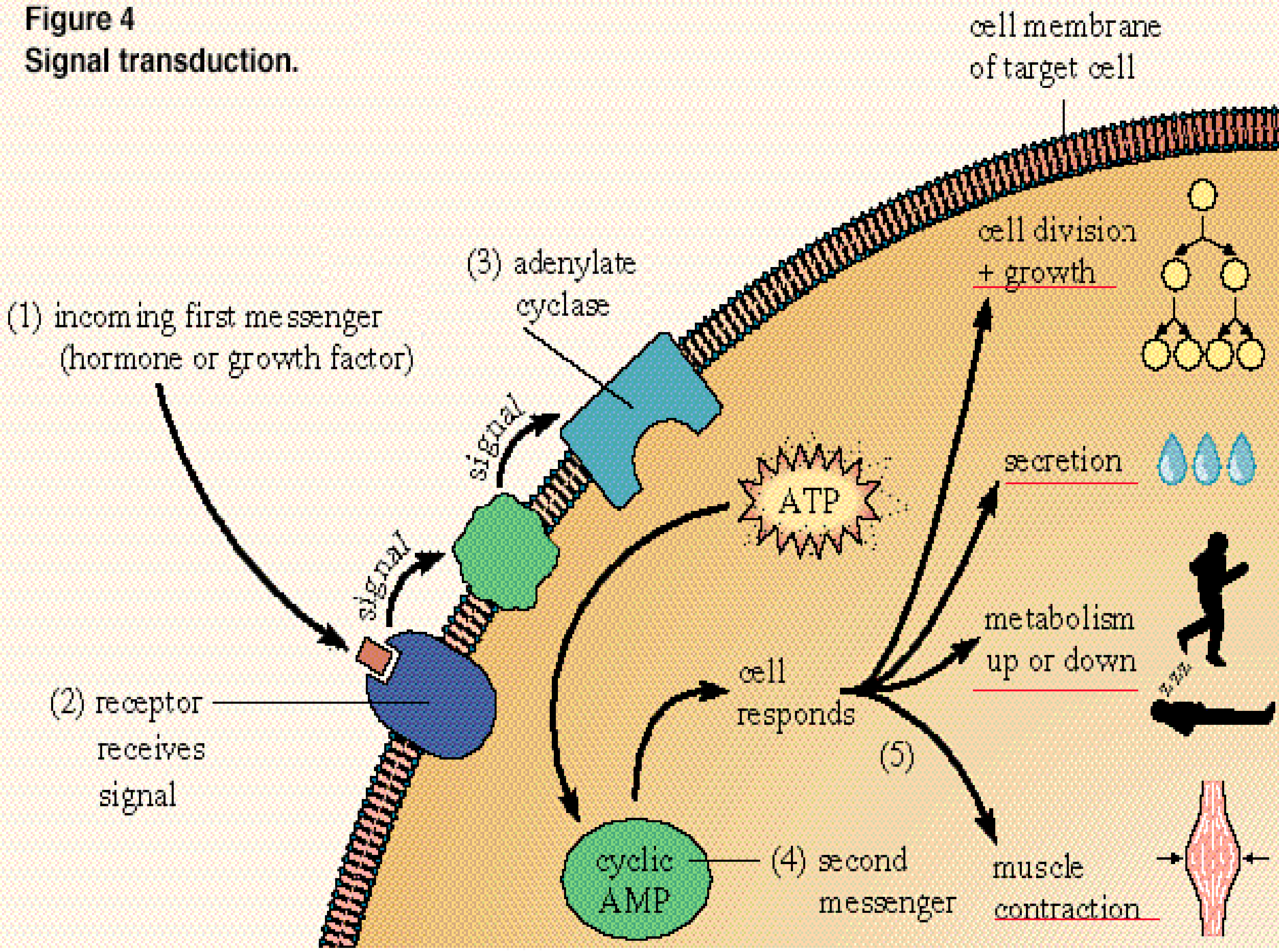

PHAGOCYTOSIS
ENDOCYTOSIS
Receptor-
mediated
endocytosis
Pinocytosis
Particle to be ingested
Particle surrounded
by cellular membrane
Plasma
membrane
Ligand
Receptor
1–2 µm
Cytosol
0.1–0.2 µm

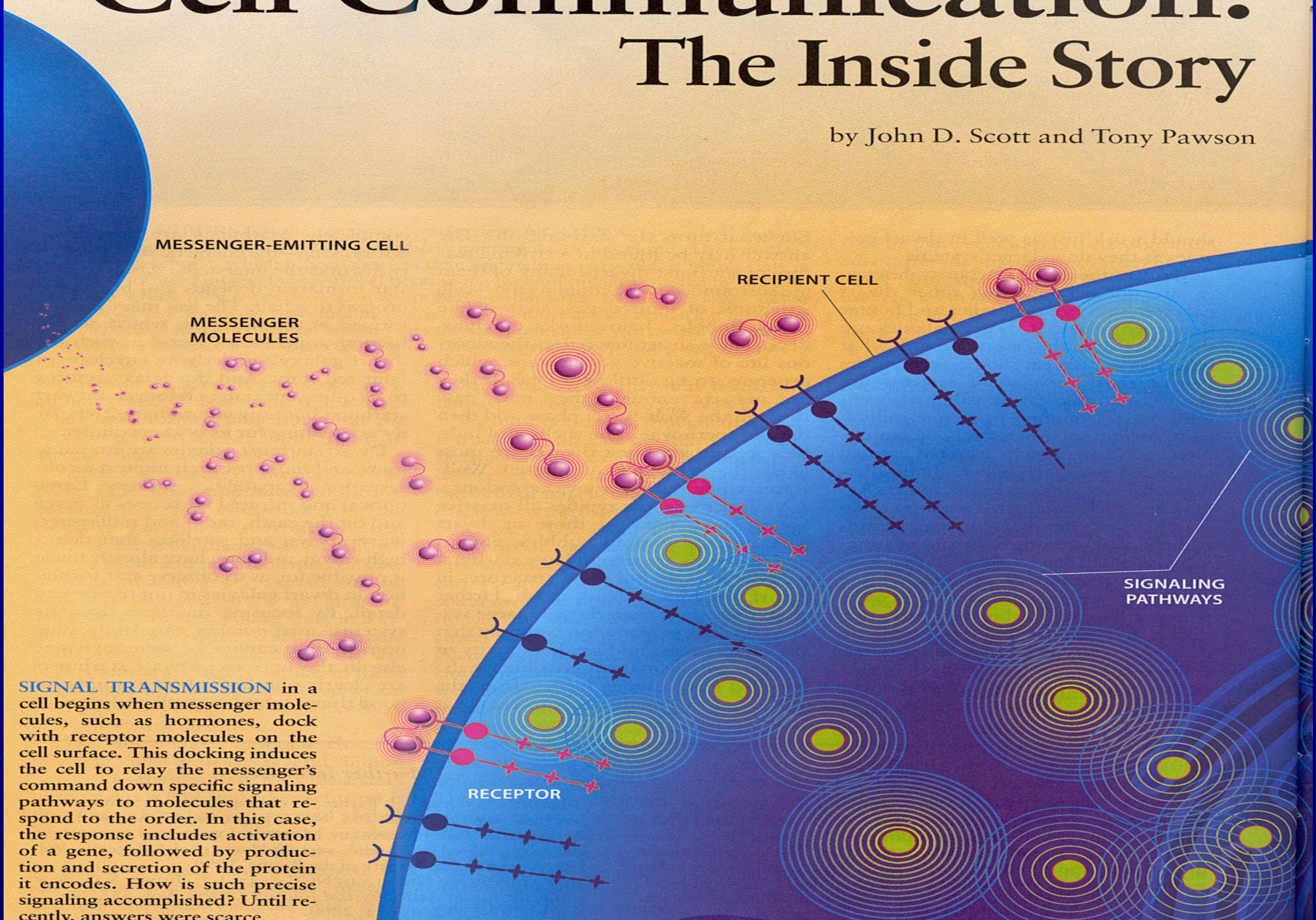
Figure 4
Signal transduction.



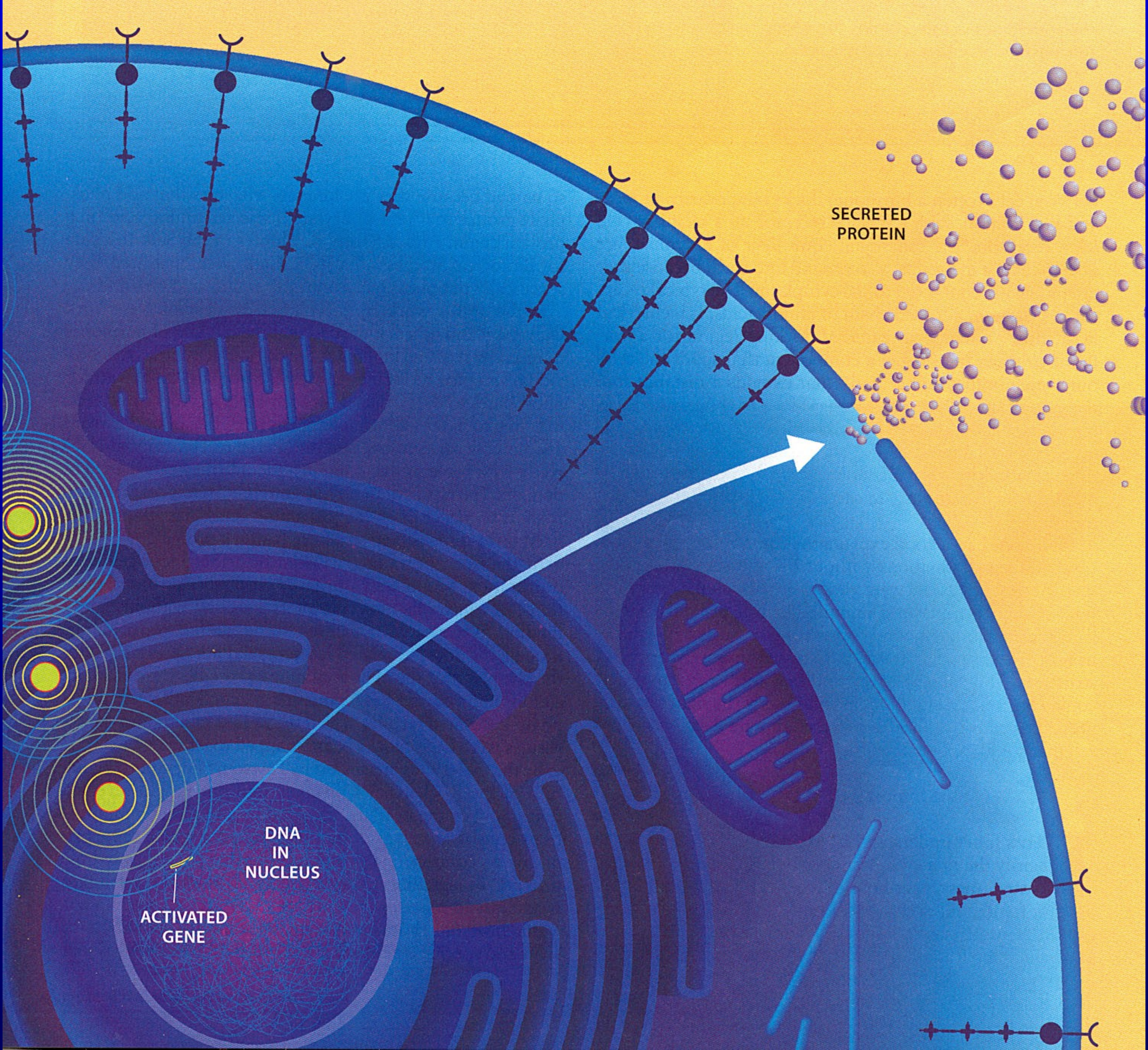
The tiny cells in our bodies harbor amazing internal communication networks. Understanding how those circuits are organized could help scientists develop new therapies for many serious disorders

Cell Communication:
The Inside Story

by John D. Scott and Tony Pawson

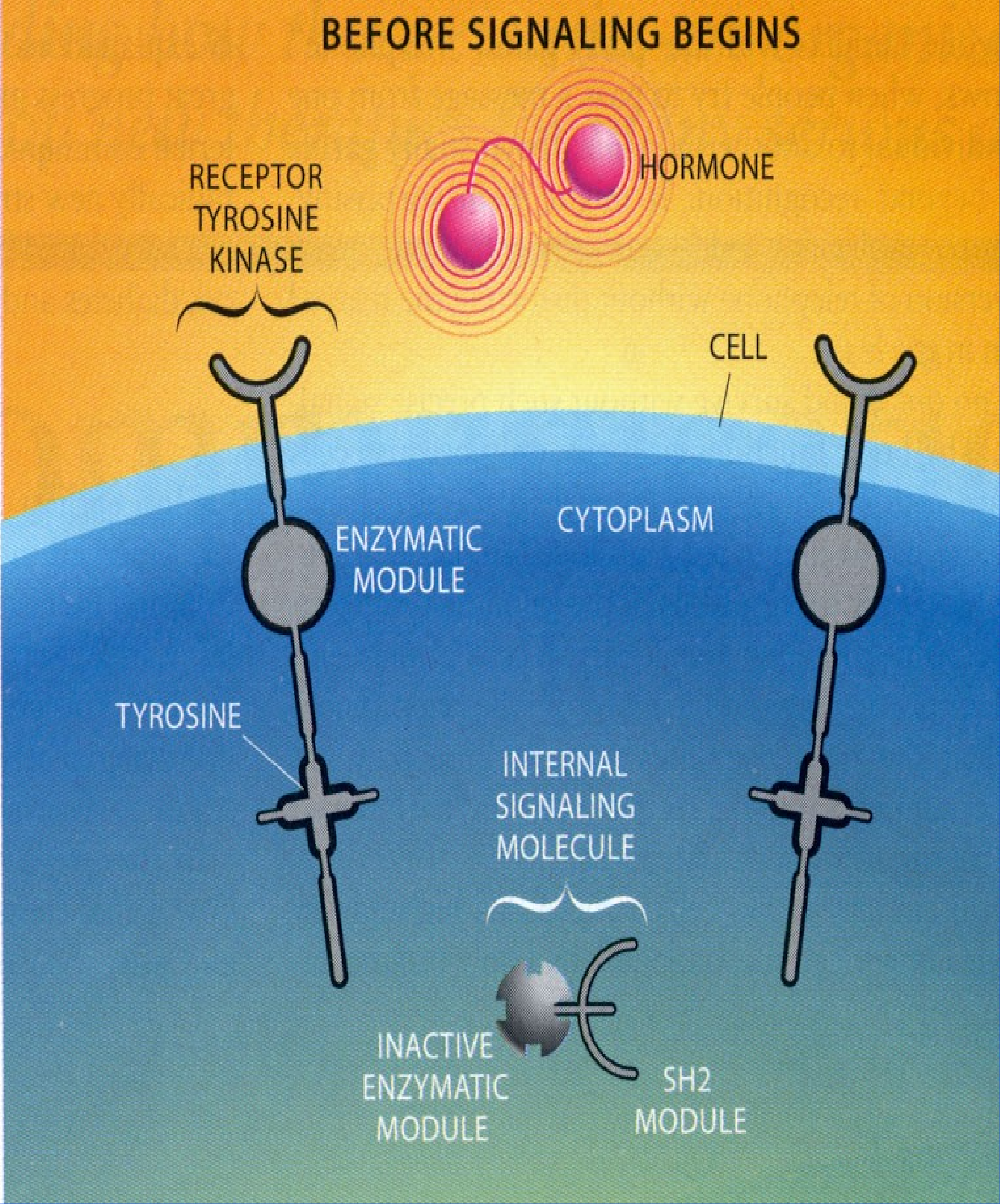


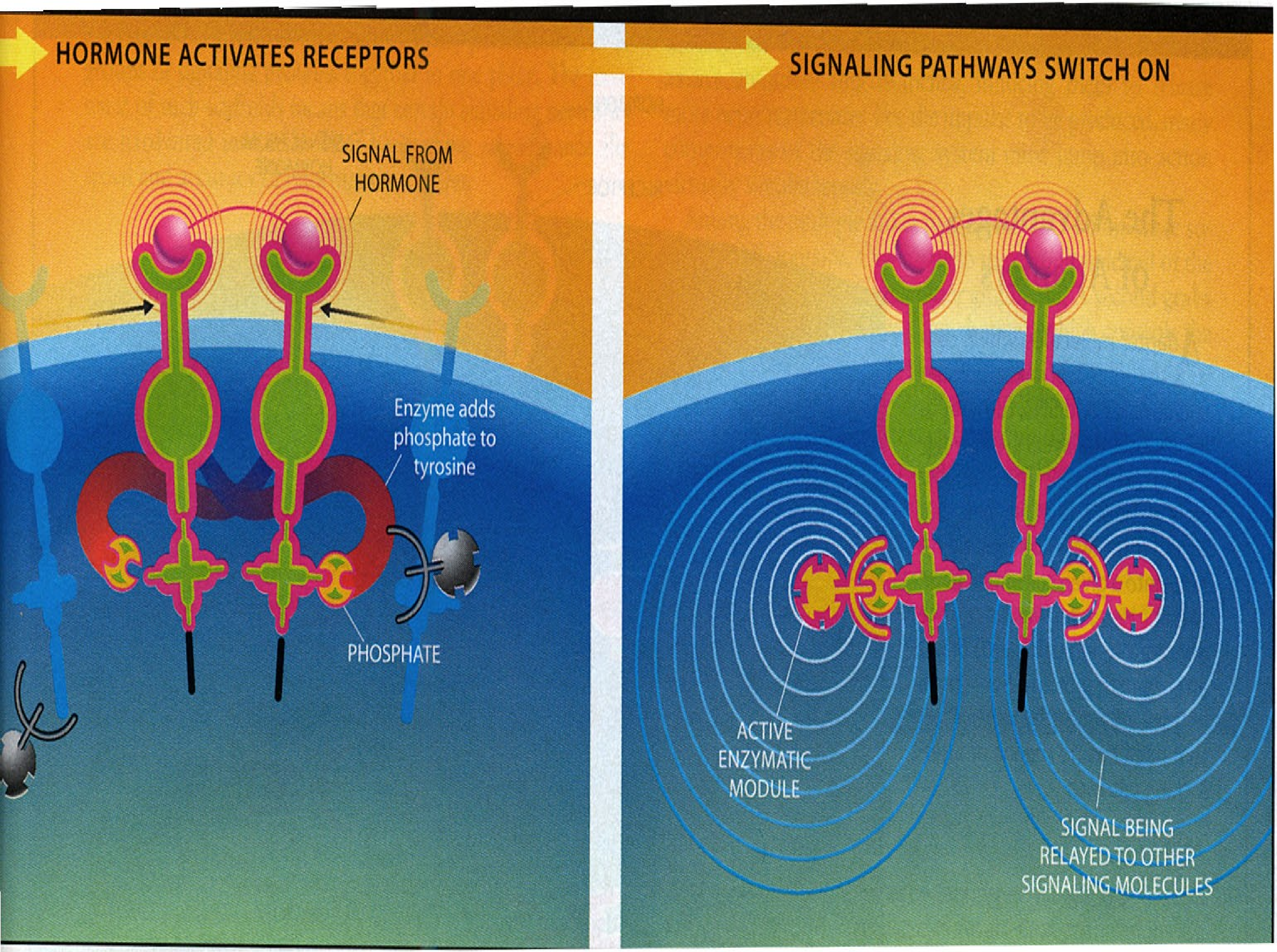
SIGNAL TRANSMISSION in a cell begins when messenger molecules, such as hormones, dock with receptor molecules on the cell surface. This docking induces the cell to relay the messenger's command down specific signaling pathways to molecules that respond to the order. In this case, the response includes activation of a gene, followed by production and secretion of the protein it encodes. How is such precise signaling accomplished? Until recently, answers were scarce.

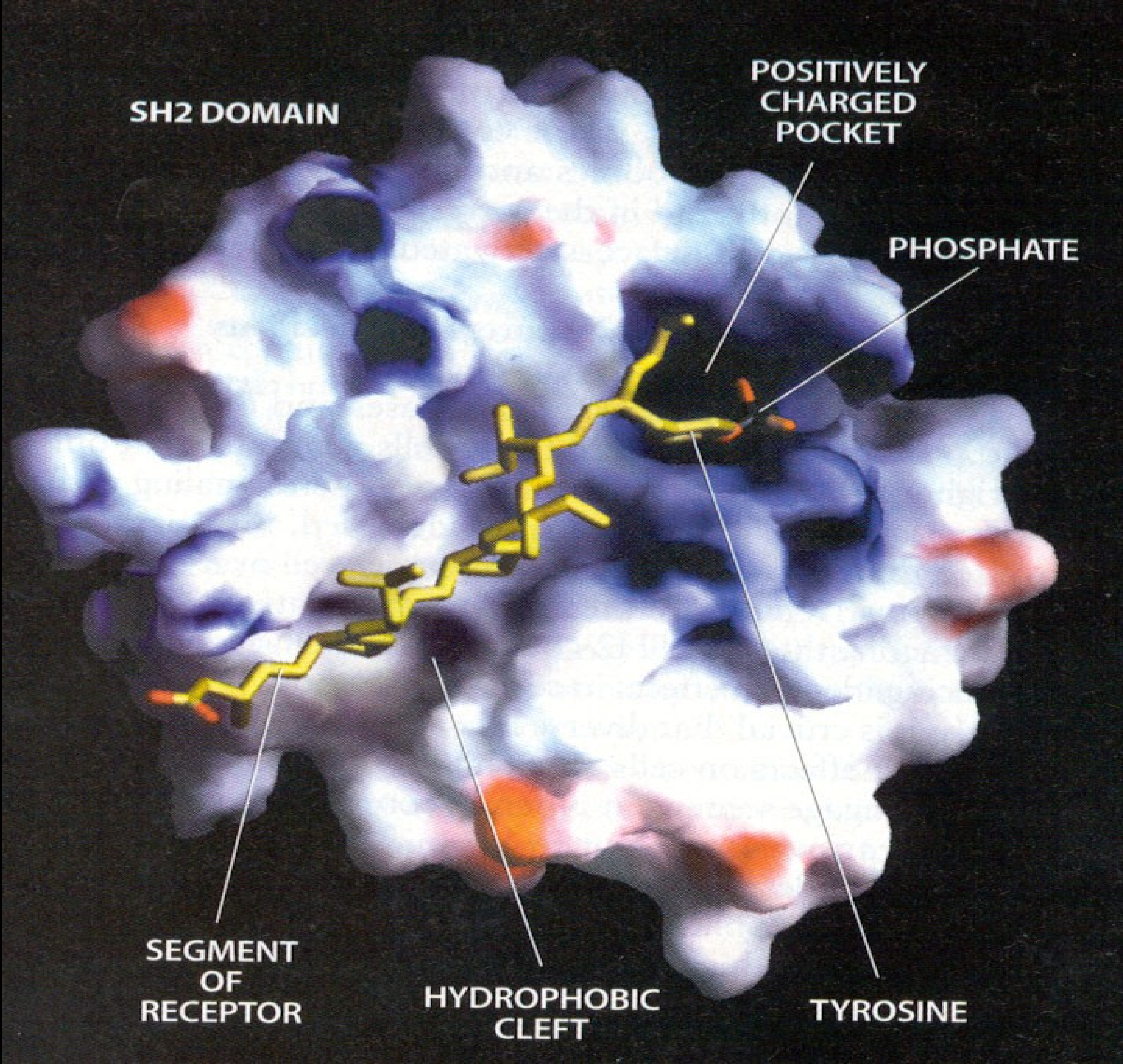

SECRETED PROTEIN
DNA IN NUCLEUS
ACTIVATED GENE

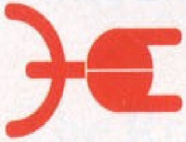
The Role of Modules in Signaling

The molecules that form signaling circuits in cells are often modular—built from components that carry out distinct tasks. This discovery emerged in part from studies of molecules known as receptor tyrosine kinases (*pogo-stick shape in first panel*). When a hormone docks with those molecules at the surface of a cell (*second panel*), the receptors pair up and add phosphates to tyrosine, an amino acid, on each other's cytoplasmic tails. Then so-called SH2 modules in certain proteins hook onto the altered tyrosines (*last panel*). This linkage enables "talkative," enzymatic modules in the proteins to pick up the messenger's order and pass it along.



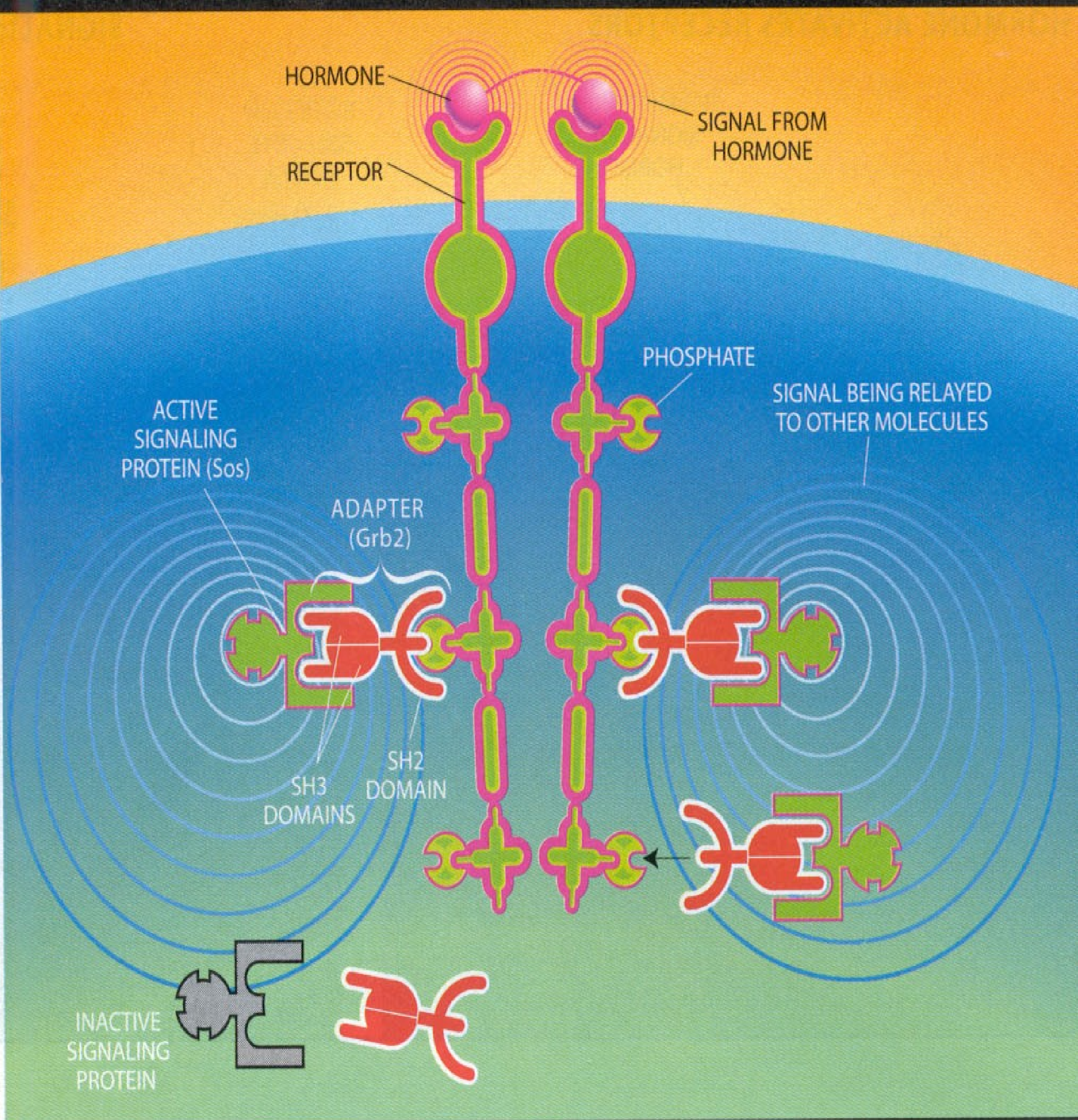

HORMONE ACTIVATES RECEPTORS
SIGNAL FROM HORMONE
Enzyme adds phosphate to tyrosine
PHOSPHATE
SIGNALING PATHWAYS SWITCH ON
ACTIVE ENZYMATIC MODULE
SIGNAL BEING RELAYED TO OTHER SIGNALING MOLECULES


SH2 DOMAIN
POSITIVELY CHARGED POCKET
PHOSPHATE
SEGMENT OF RECEPTOR
HYDROPHOBIC CLEFT
TYROSINE



The Advantages of Adapters

Adapter molecules, which consist entirely of linker modules such as SH2 and SH3, turn out to be important players in many signaling pathways. They enable cells to make use of proteins that would otherwise be unable to hook into a given communication circuit. Here, for instance, the adapter protein Grb2 (*red*) draws an enzymatic protein—Sos—into a pathway headed by a receptor that itself has no means of interlocking with Sos.



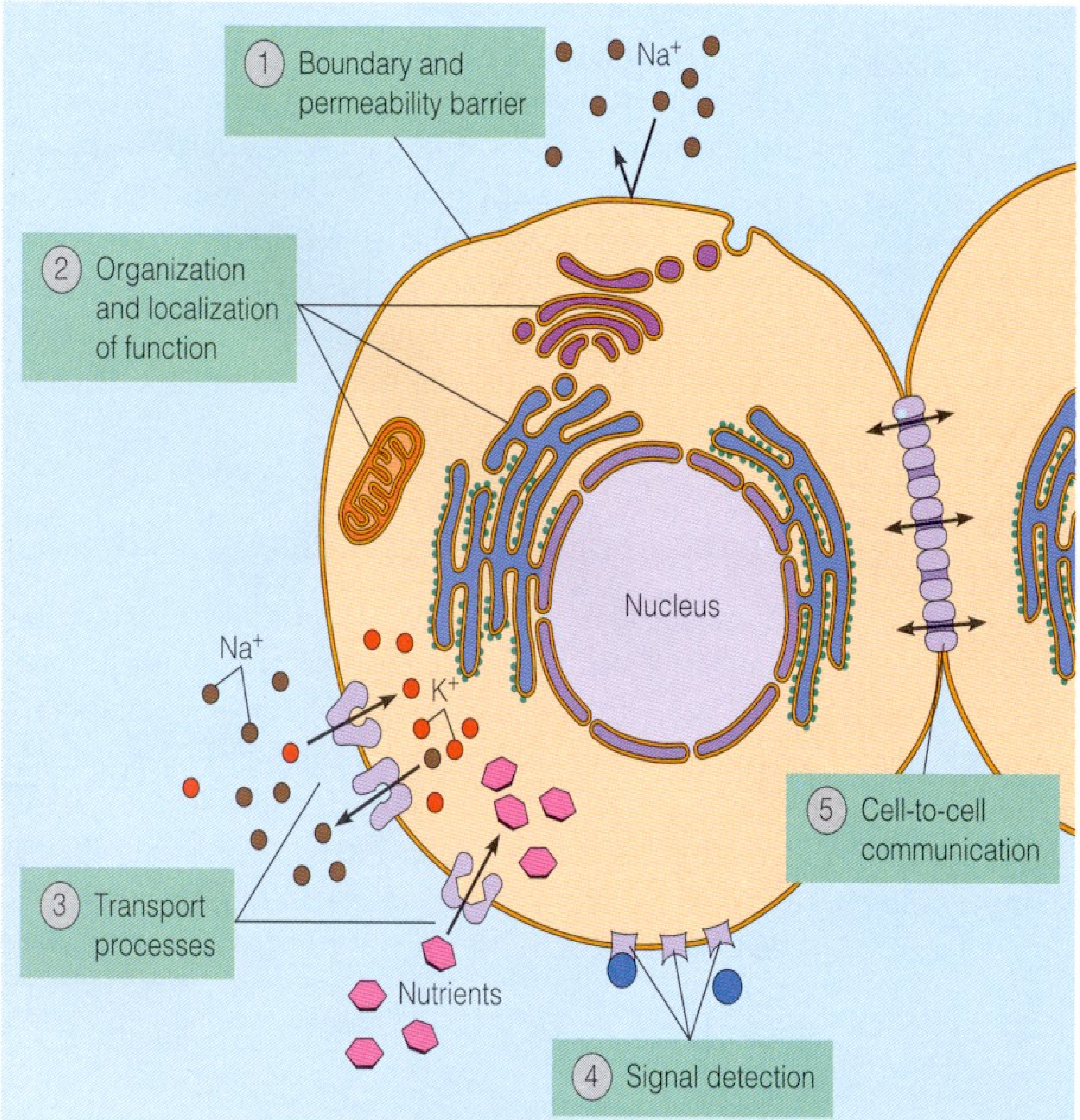


Figure 7-2 Functions of Membranes. Membranes ① define the boundaries of the cell and its organelles, ② serve as loci for specific functions, ③ provide for and regulate transport processes, ④ contain the receptors needed to detect external signals, and ⑤ provide mechanisms for cell-to-cell contact and communication.

CYTOPLASM

Cytoplasm

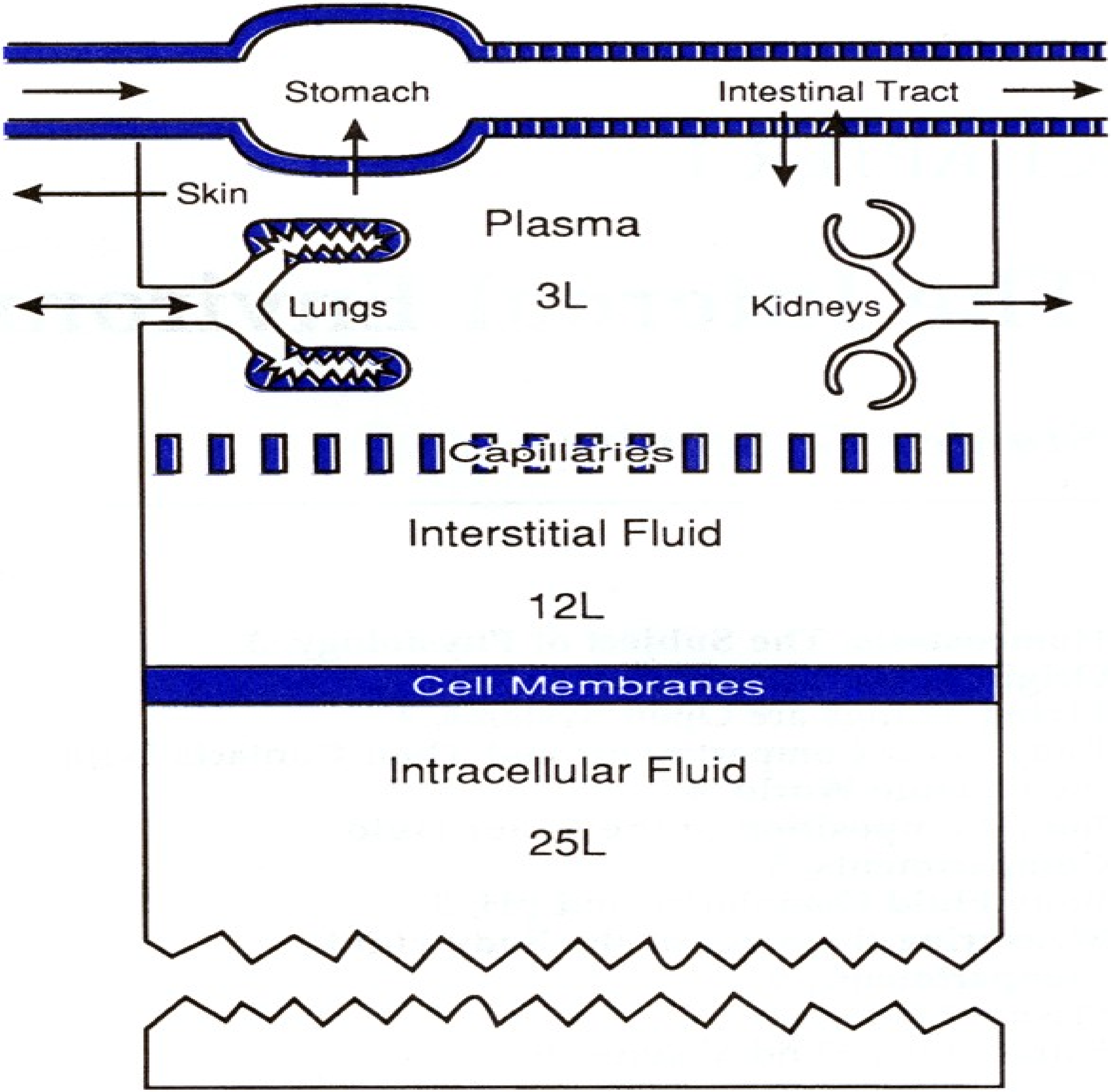
- The chemicals in cytosol are either in solution or in a colloidal (suspended) form.
- Functionally, cytosol is the medium in which many metabolic reactions occur.

Cytoplasm

- *Cytosol*, the intracellular fluid, is the semifluid portion of cytoplasm that contains inclusions and dissolved solutes, composed mostly of water, plus proteins, carbohydrates, lipids, and inorganic substances.

Cytosol

- Metabolic reaction medium
- The intracellular fluid
  - 75-90% water
  - 10-25% “solids”
    - Proteins, carbohydrates, lipids
    - Inorganic substances
    - Organic substances
      - Colloid


Stomach
Intestinal Tract
Skin
Plasma
3L
Lungs
Kidneys
Capillaries
Interstitial Fluid
12L
Cell Membranes
Intracellular Fluid
25L

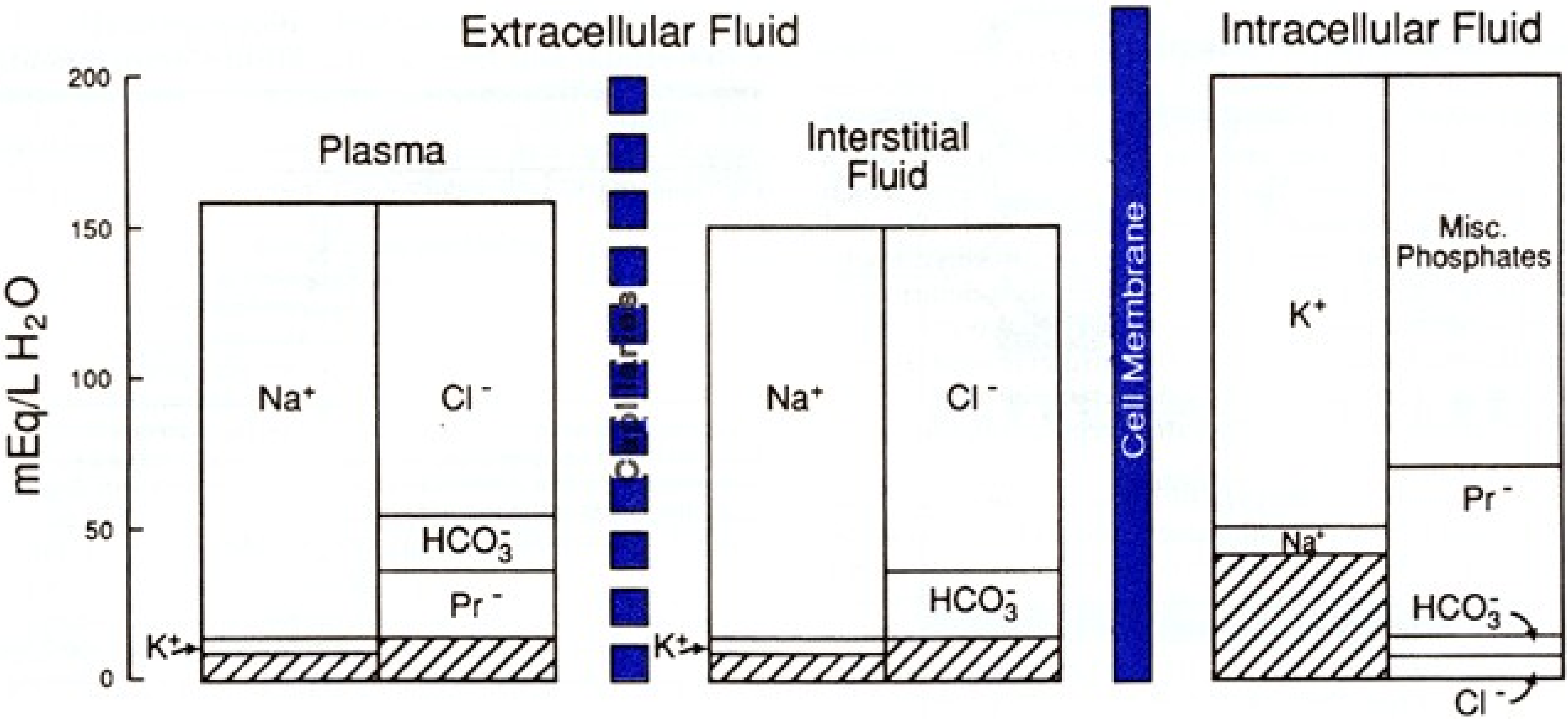
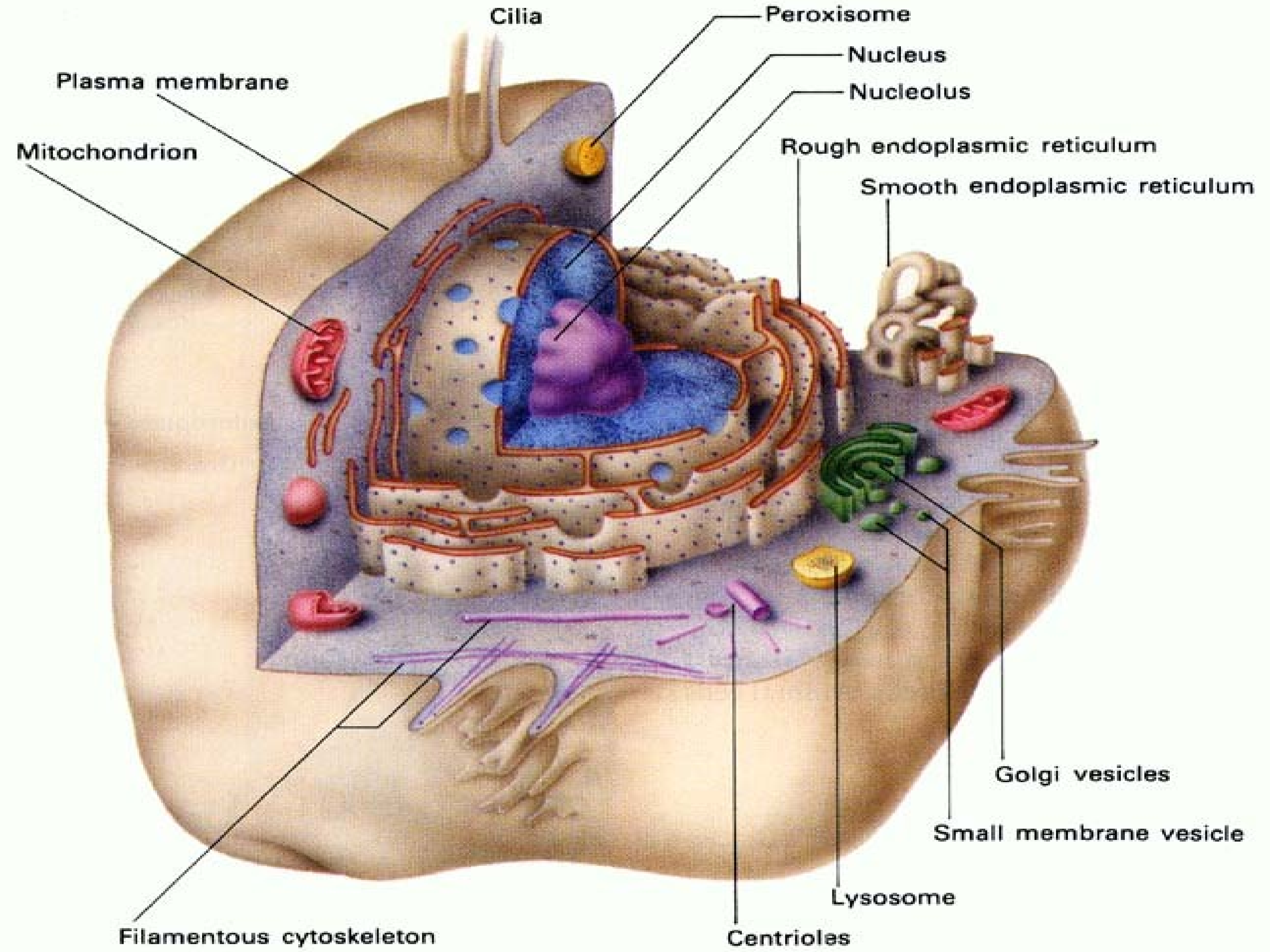
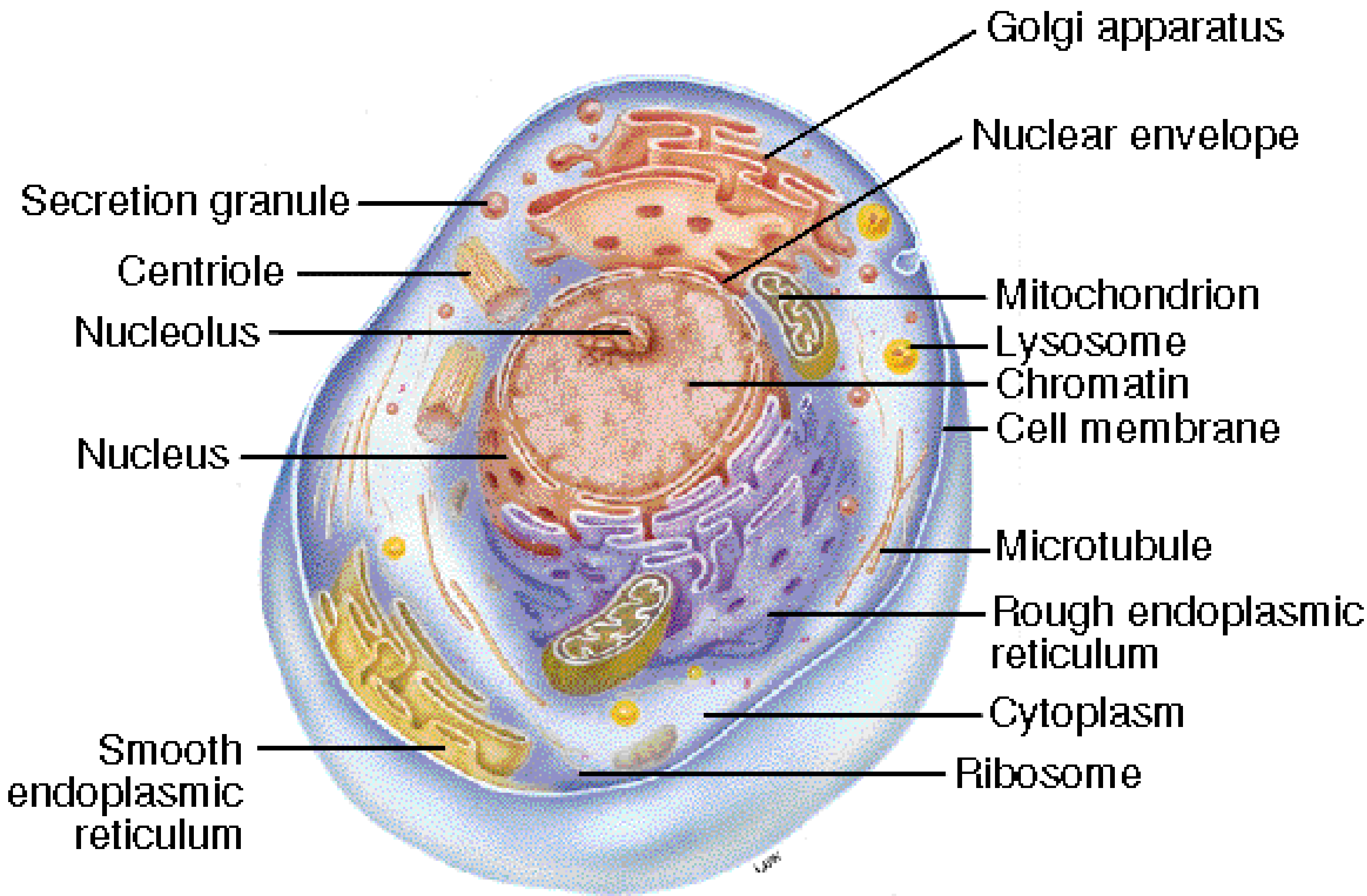

Extracellular Fluid
Intracellular Fluid
mEq/L H_2O
200
150
100
50
0
Plasma
Na+
Cl -
HCO3-
Pr -
K+
Capillaries
Interstitial Fluid
Na+
Cl -
HCO3-
K+
Cell Membrane
K+
Misc. Phosphates
Pr -
Na+
HCO3-
Cl -

TABLE 1 Important Components of Extracellular and Intracellular Fluid Compartments

	Extracellular[a]	Intracellular[b]
Ca^{2+} (mmol/L)	2.5	1×10^{-4}
Cl^- (mmol/L)	110	~10
HCO_3 (mmol/L)	20	~10
K^+ (mmol/L)	4	120
Na^+ (mmol/L)	140	14
Osmolarity (mOsm/L)	295	295
pH	7.4	7.1–7.2


Cilia
Peroxisome
Nucleus
Nucleolus
Plasma membrane
Mitochondrion
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Golgi vesicles
Small membrane vesicle
Lysosome
Filamentous cytoskeleton
Centrioles

Generalized Cell. Figure 3.1



Organelles

- Organelles are specialized structures that have characteristic shapes and perform specific functions in cellular growth, maintenance, and reproduction.
  - Cytoskeleton; Centrosomes; Ribosomes
  - Endoplasmic Reticulum; Golgi Complex
  - Lysosomes; Peroxisomes
  - Mitochondria

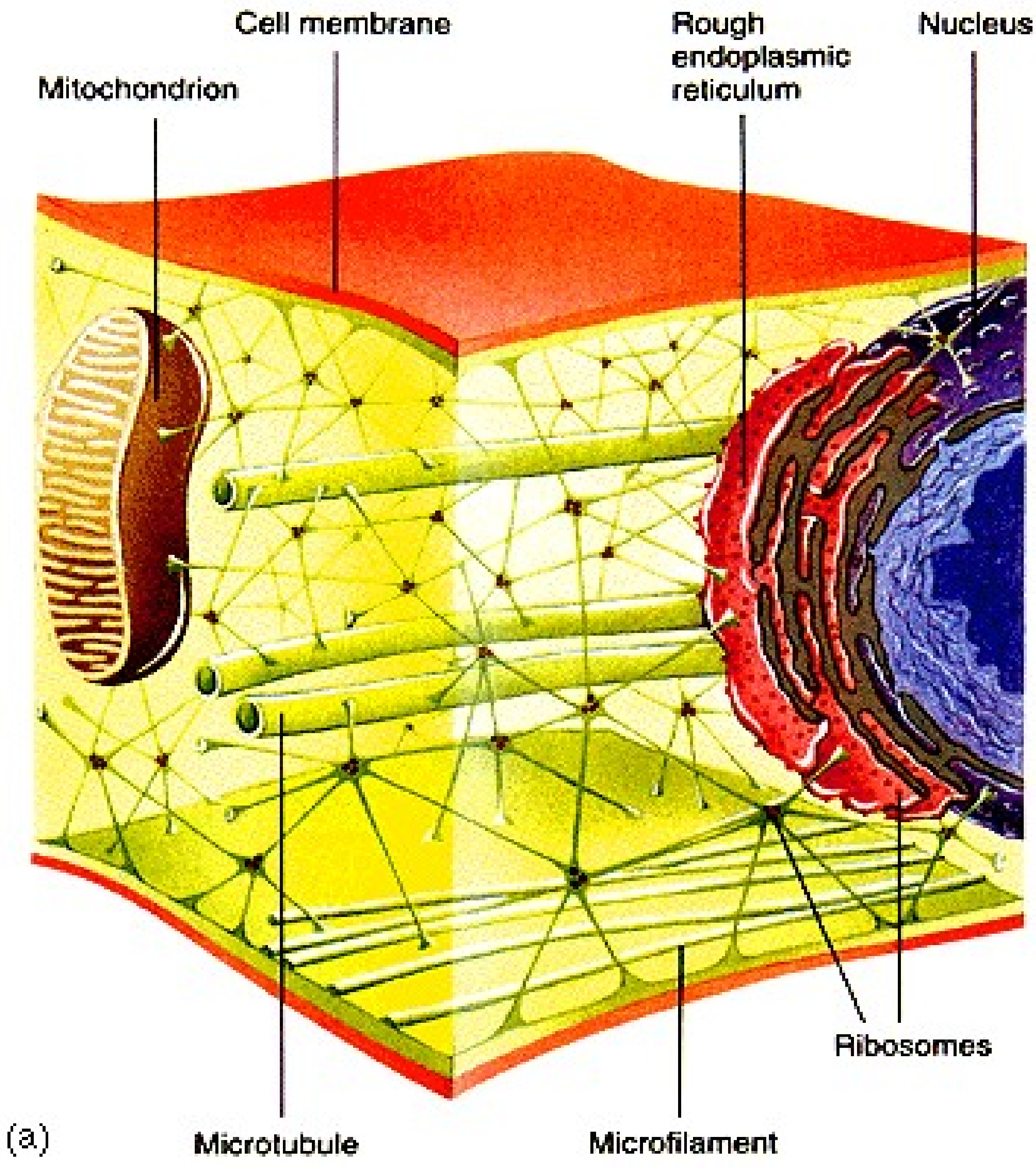
The Cytoskeleton

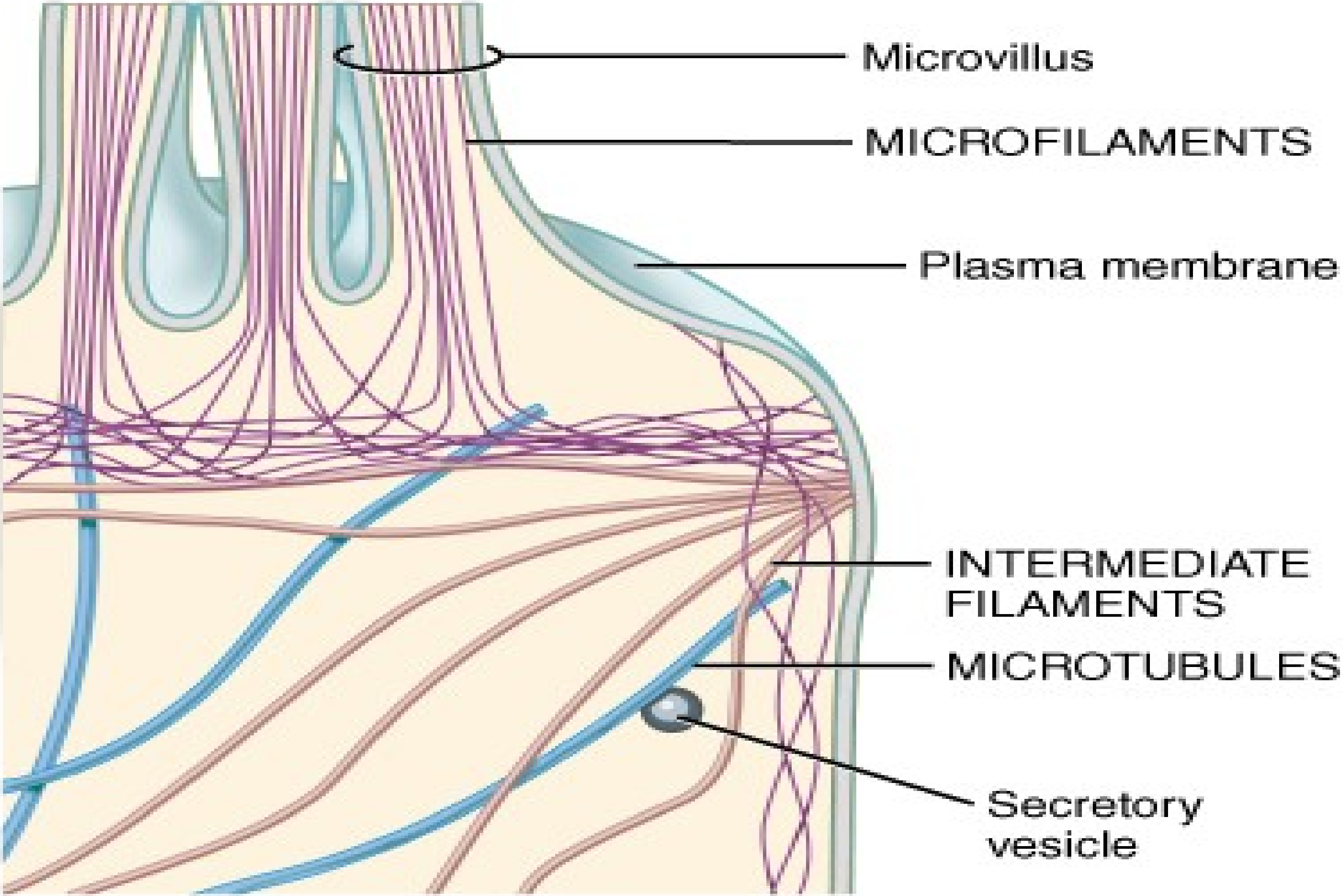
- A network of several kinds of protein filaments that extend throughout the cytoplasm and provides a structural framework for the cell (Fig. 3.16).
  - It consists of microfilaments, intermediate filaments, and microtubules.
  - Most microfilaments are composed of **actin** and function in movement and mechanical support.

The Cytoskeleton

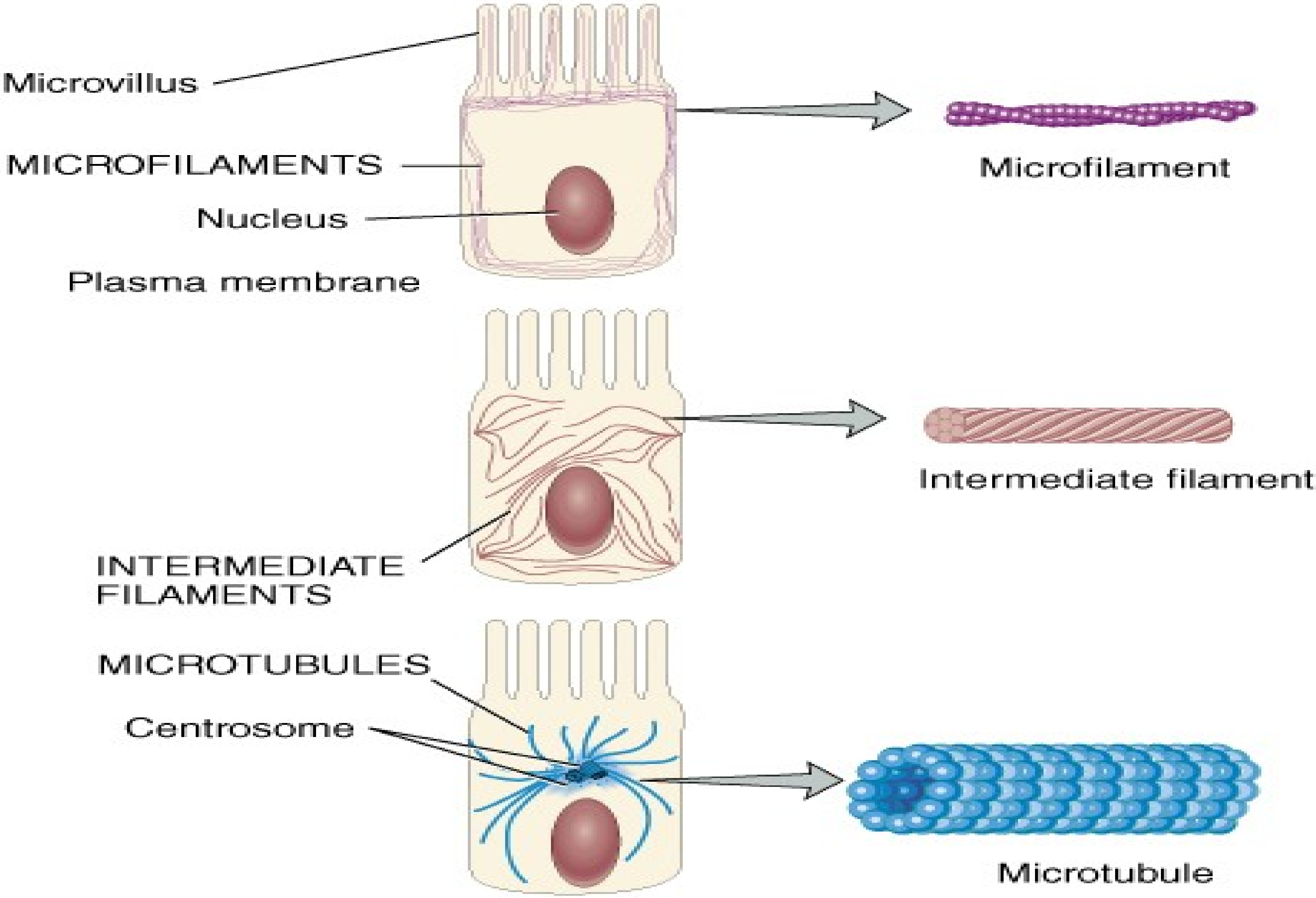
- Intermediate filaments are composed of several different proteins and function in support and to help anchor organelles such as the nucleus (Fig. 3.16a and b).
- Microtubules are composed of a protein called tubulin and help determine cell shape and function in the intracellular transport of organelles and the migration of chromosome during cell division.

Microtubules.

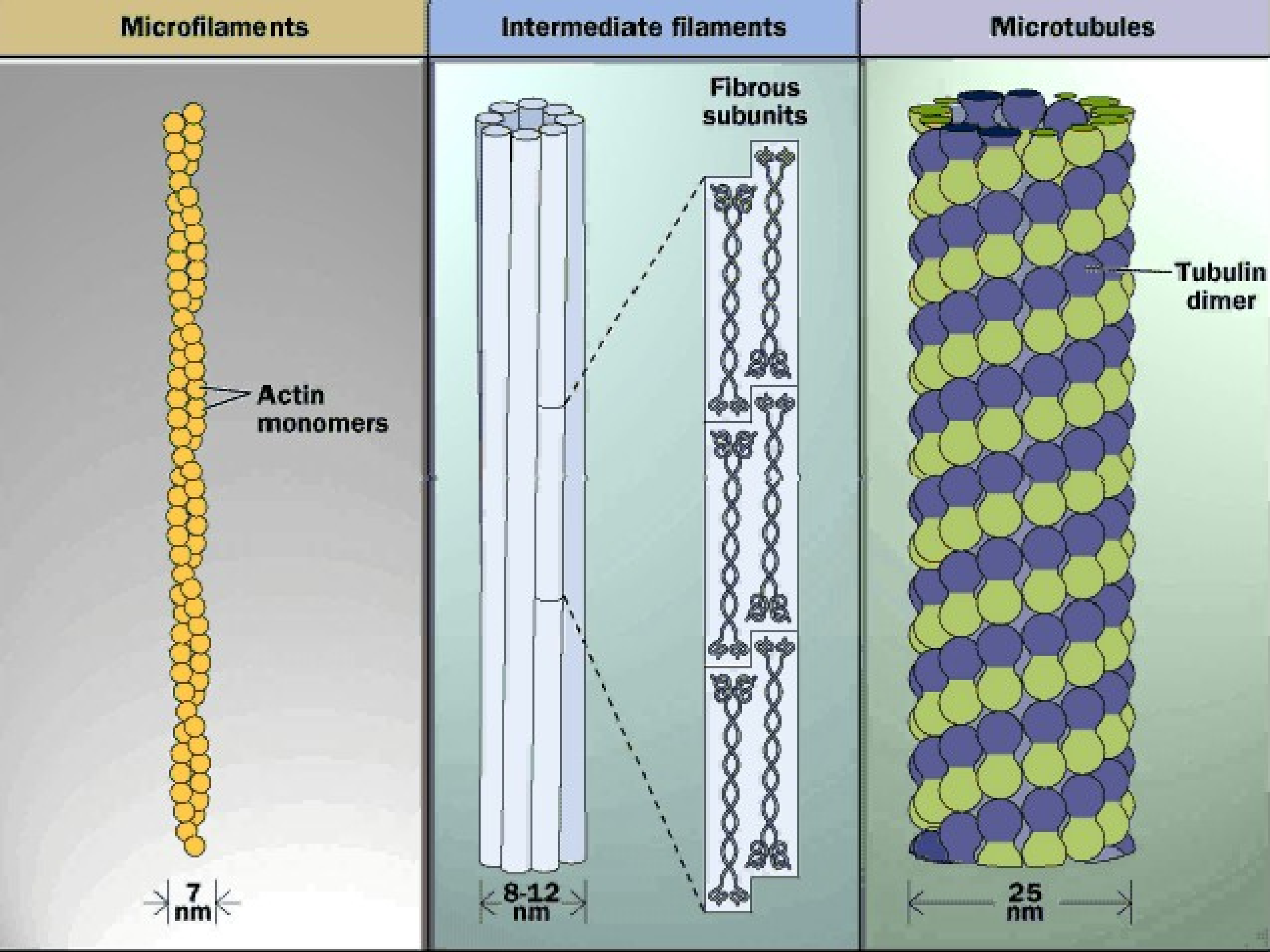




(a) Overview of cytoskeleton

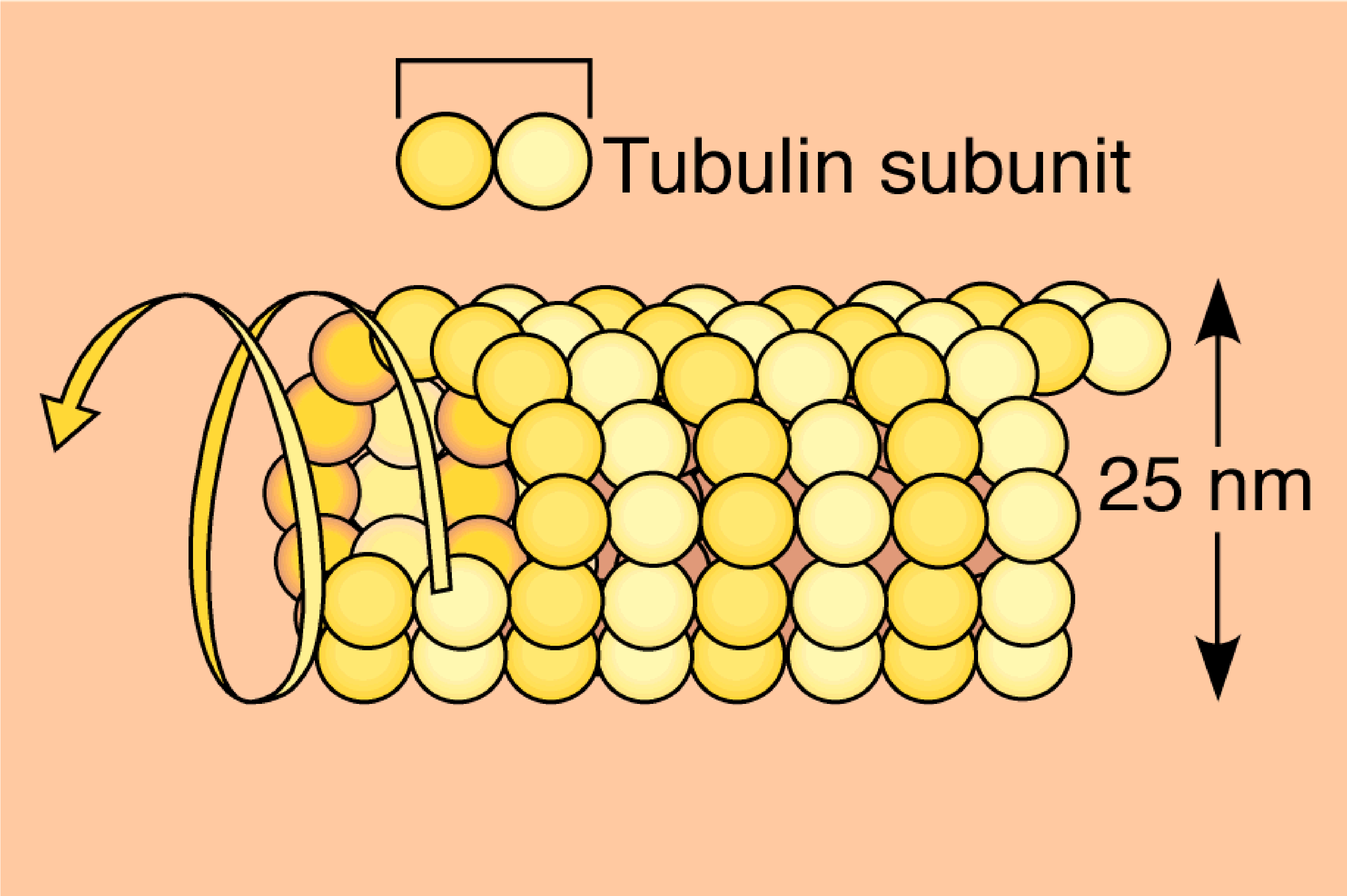


(b) Distribution of cytoskeletal elements (left) and detail of structure (right)

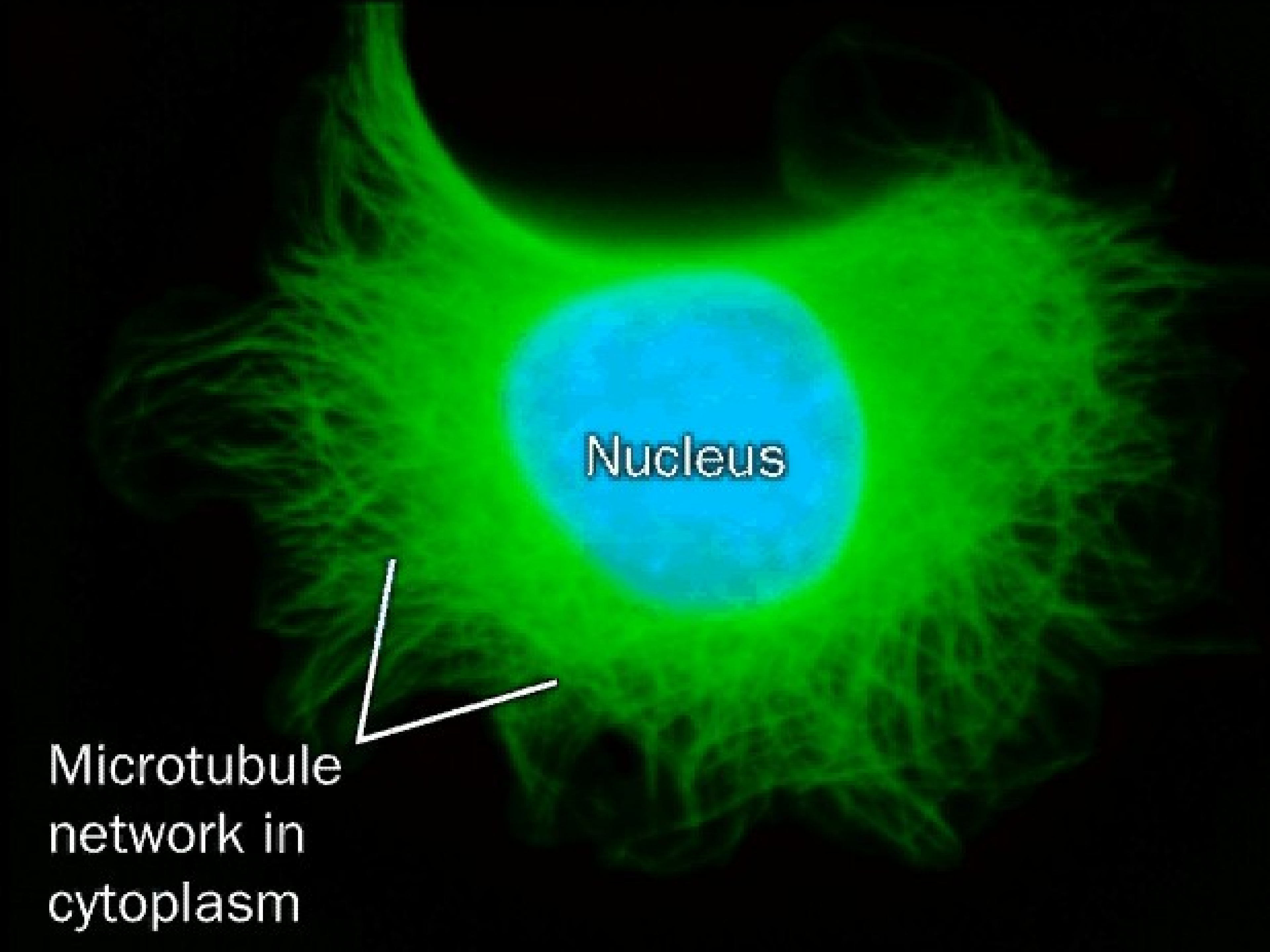

Microfilaments
Intermediate filaments
Microtubules
Actin monomers
7 nm
Fibrous subunits
8-12 nm
Tubulin dimer
25 nm

Microtubule

Microtubules are long tubular structures composed of tubulin. They have distinct ends, called the - and + ends. Microtubules are a major component of the cytoskeleton, playing roles in chromosome movement, cell motility, and polarity of eukaryotic cells. They constitute the spindle in mitosis and meiosis. They grow out from microtubule organizing centers (MTOCs). The network of microtubules can determine where the center of the cell lies.

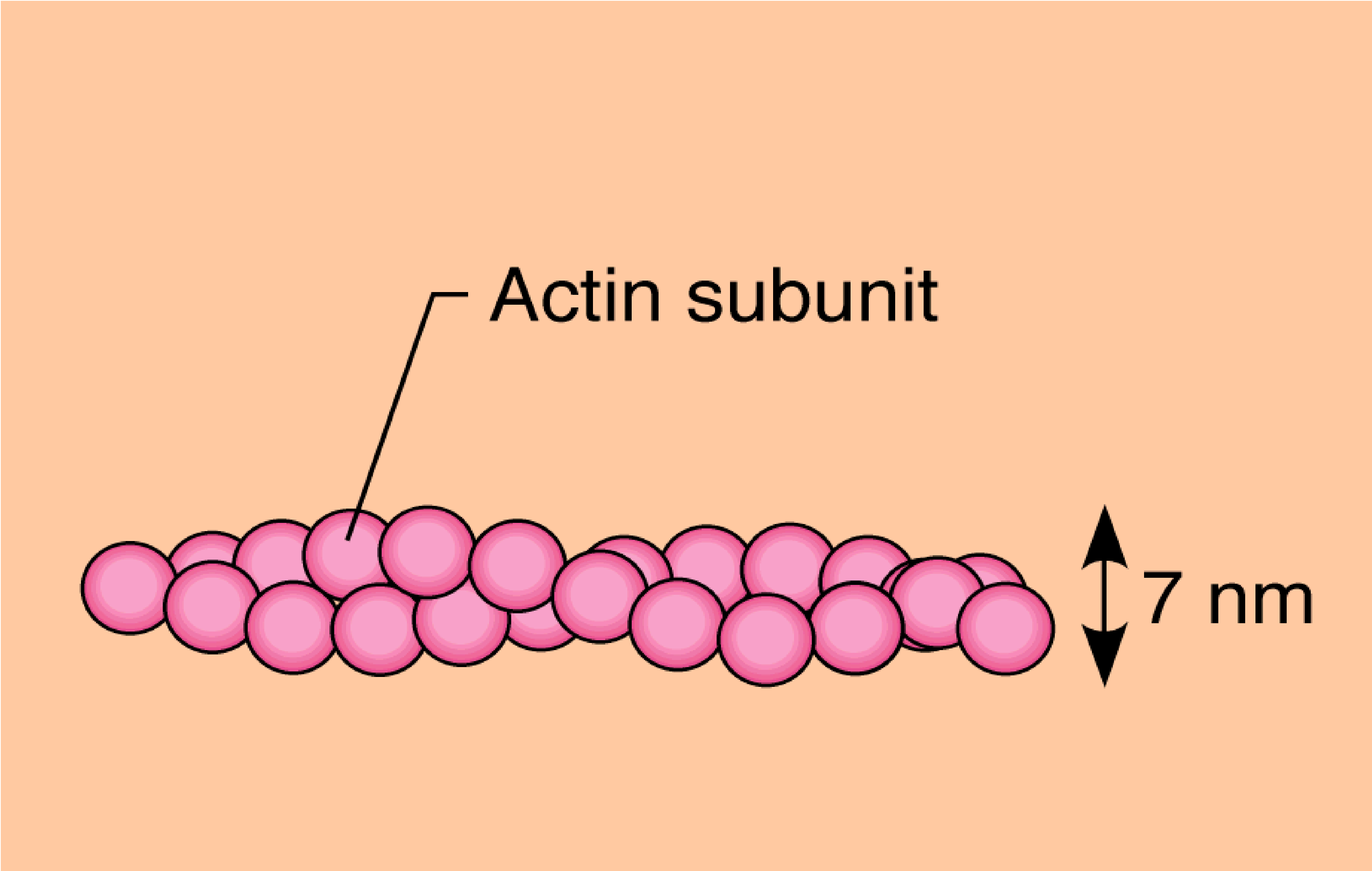


(a) Microtubule

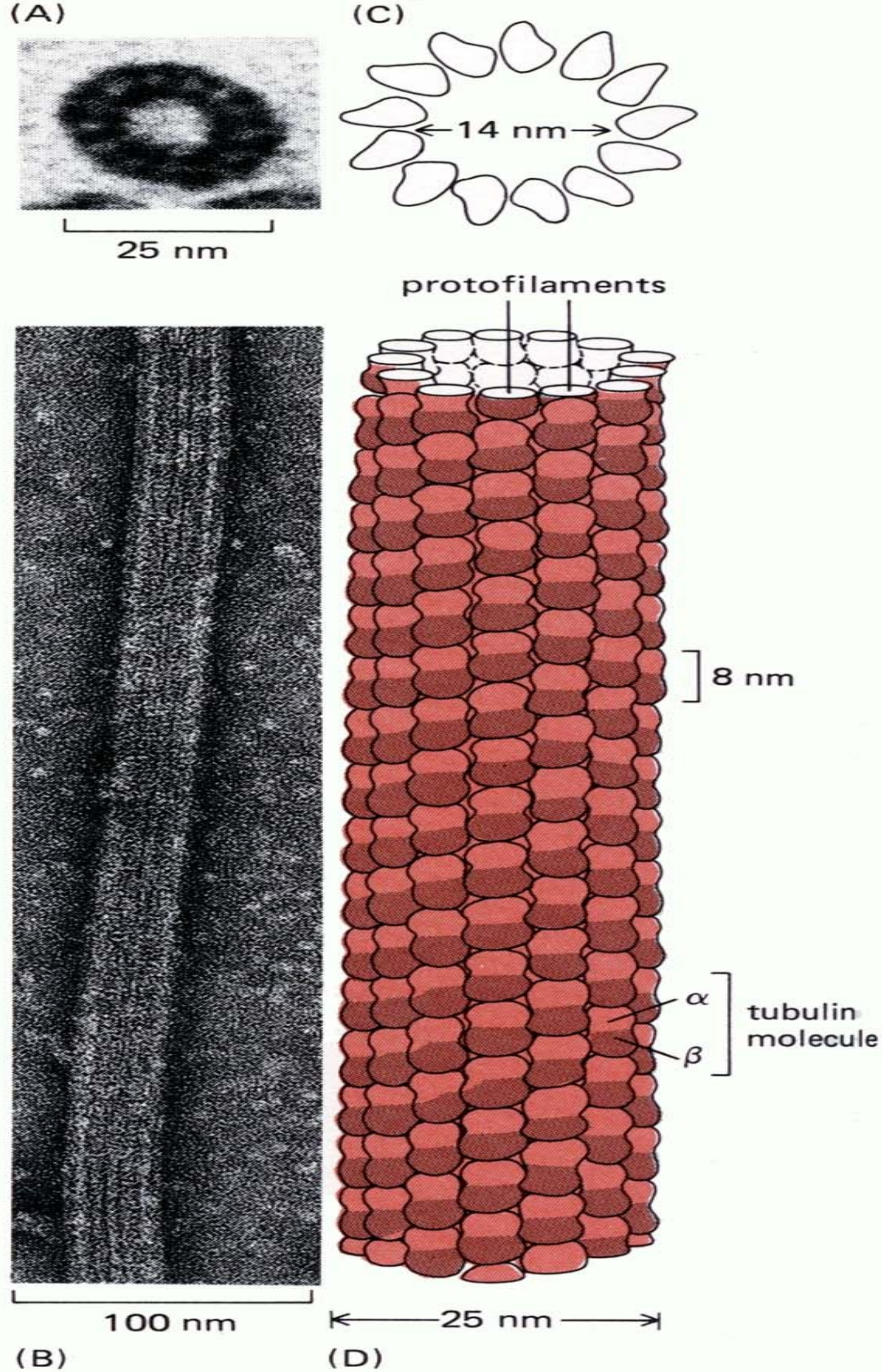

Nucleus
Microtubule network in cytoplasm

Microfilament

Microfilaments, or actin filaments, are an important element of the cytoskeleton of a eukaryotic cell. The filaments, or F-actin, form by the polymerization of globular actin (G-actin). Microfilaments are a key part of the cellular machinery of muscle contraction. As cytoskeletal components, microfilaments bind a variety of proteins, causing responses such as cellular movement, cytokinesis, and others.

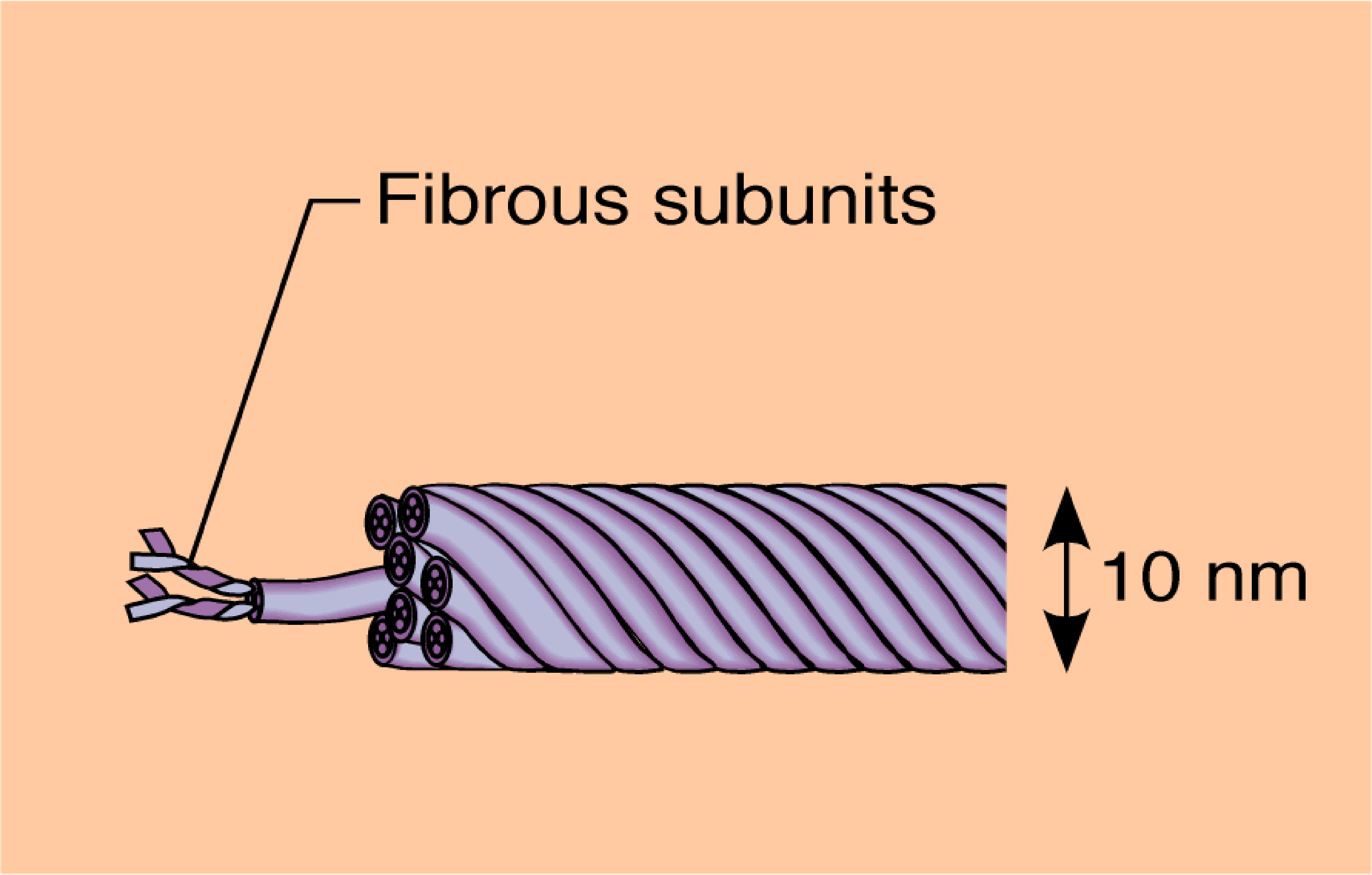


(b) Microfilament

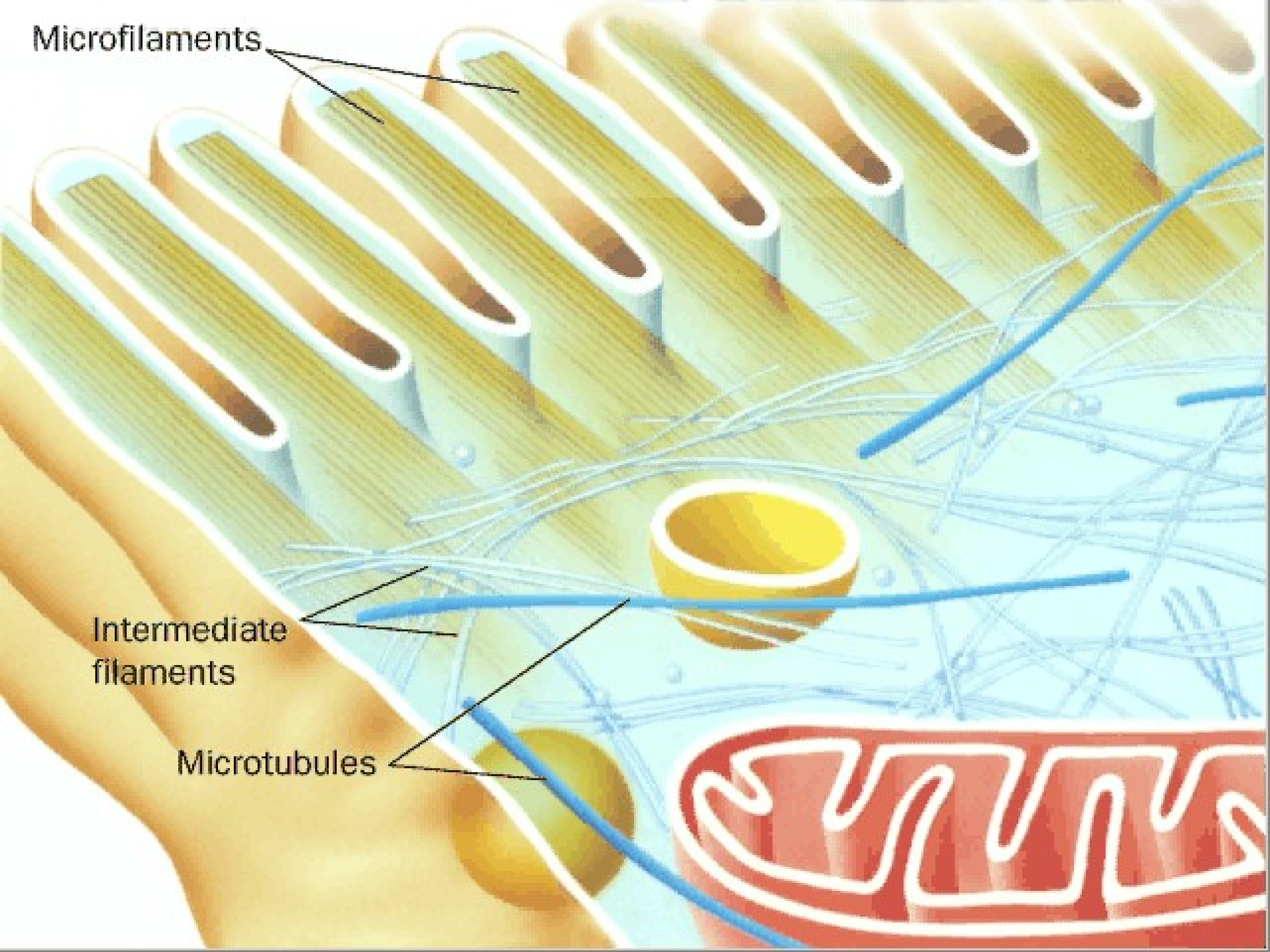

(A)
25 nm
(C)
14 nm
protofilaments
8 nm
α
β
tubulin
molecule
100 nm
25 nm
(B)
(D)

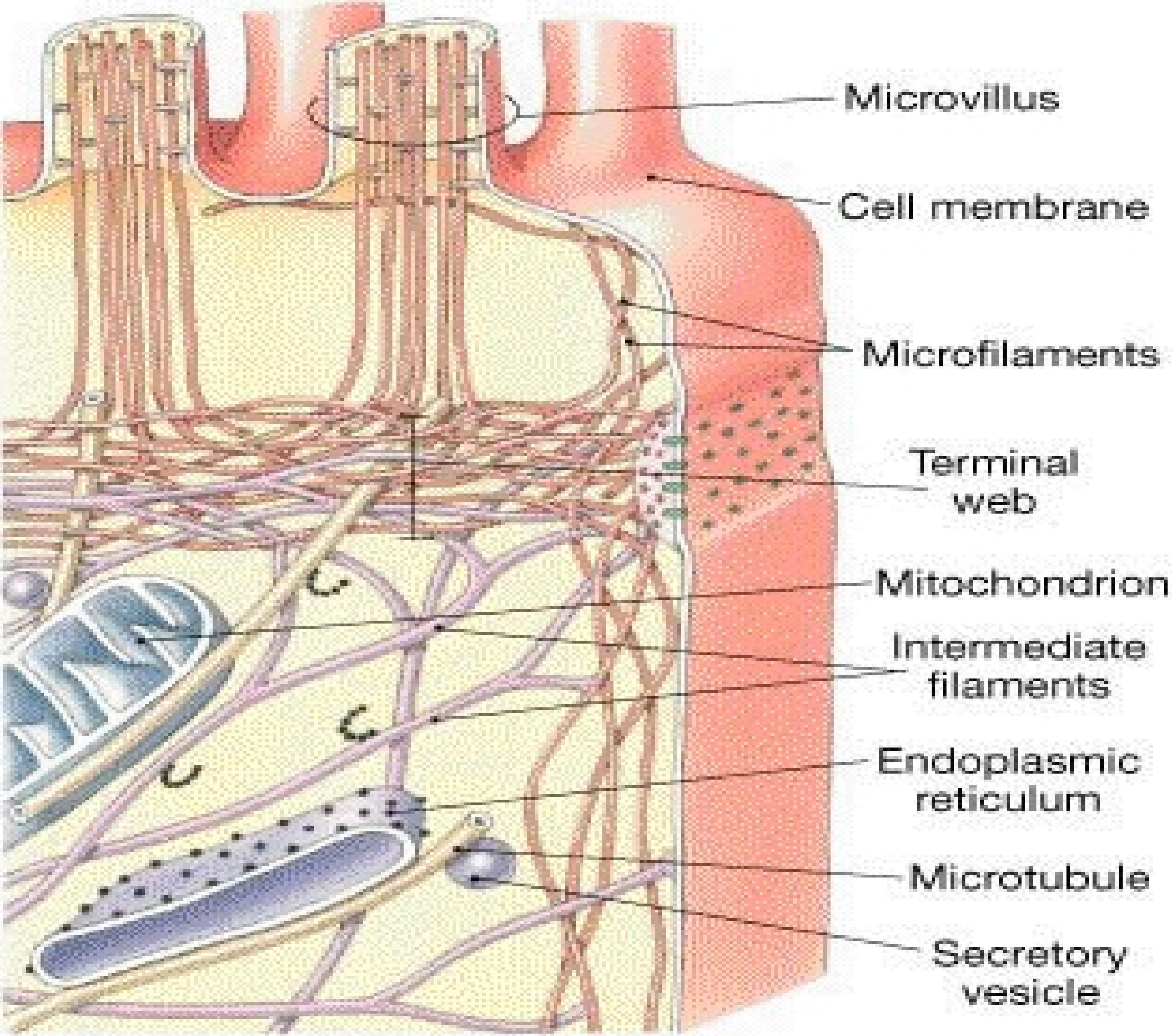
Intermediate filament

Intermediate filaments are components of the cytoskeleton that are intermediate in size between microfilaments and microtubules. They stabilize cell structure and resist tension. Intermediate filaments form ropelike networks.

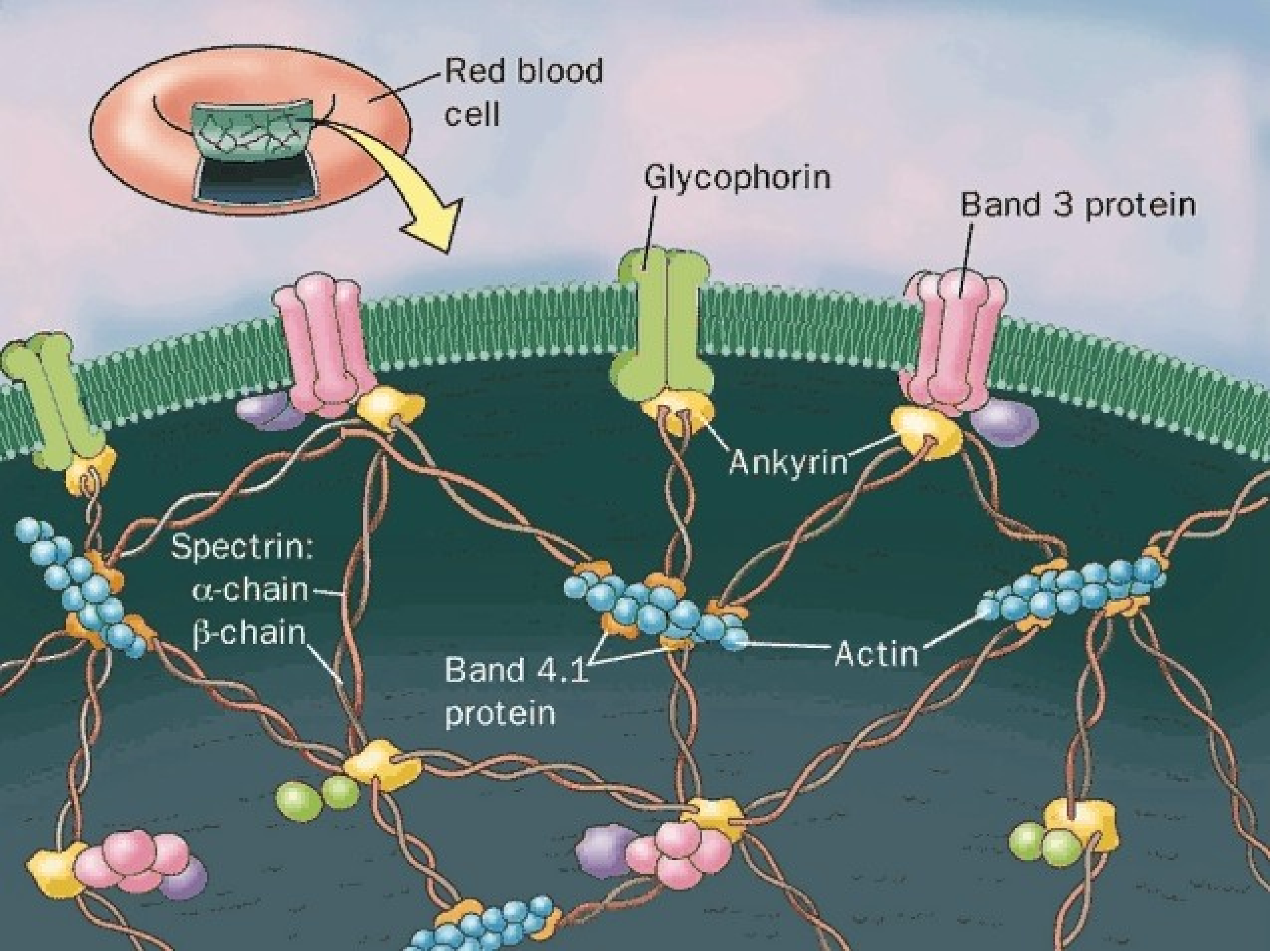


(c) Intermediate filament

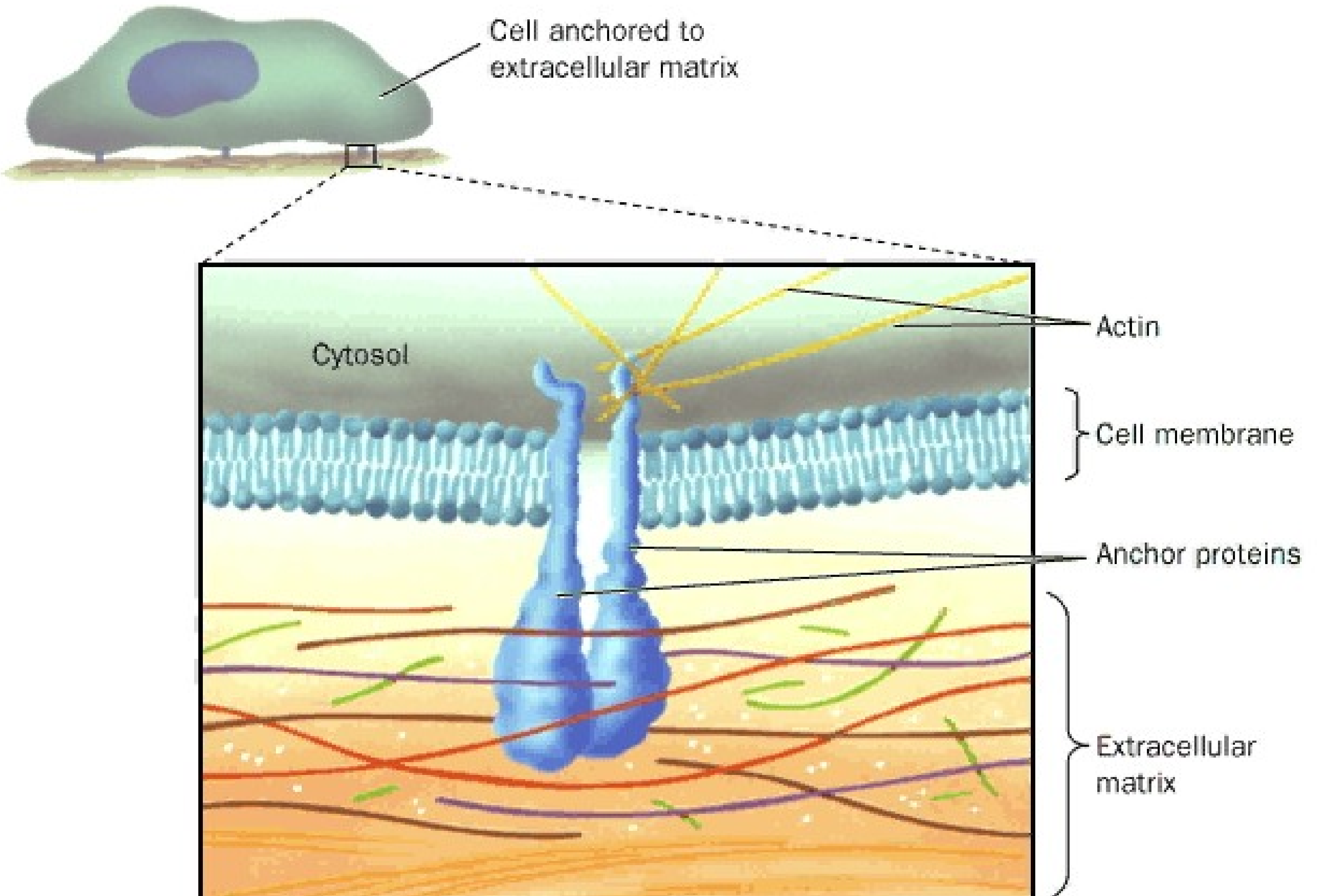

Microfilaments
Intermediate filaments
Microtubules

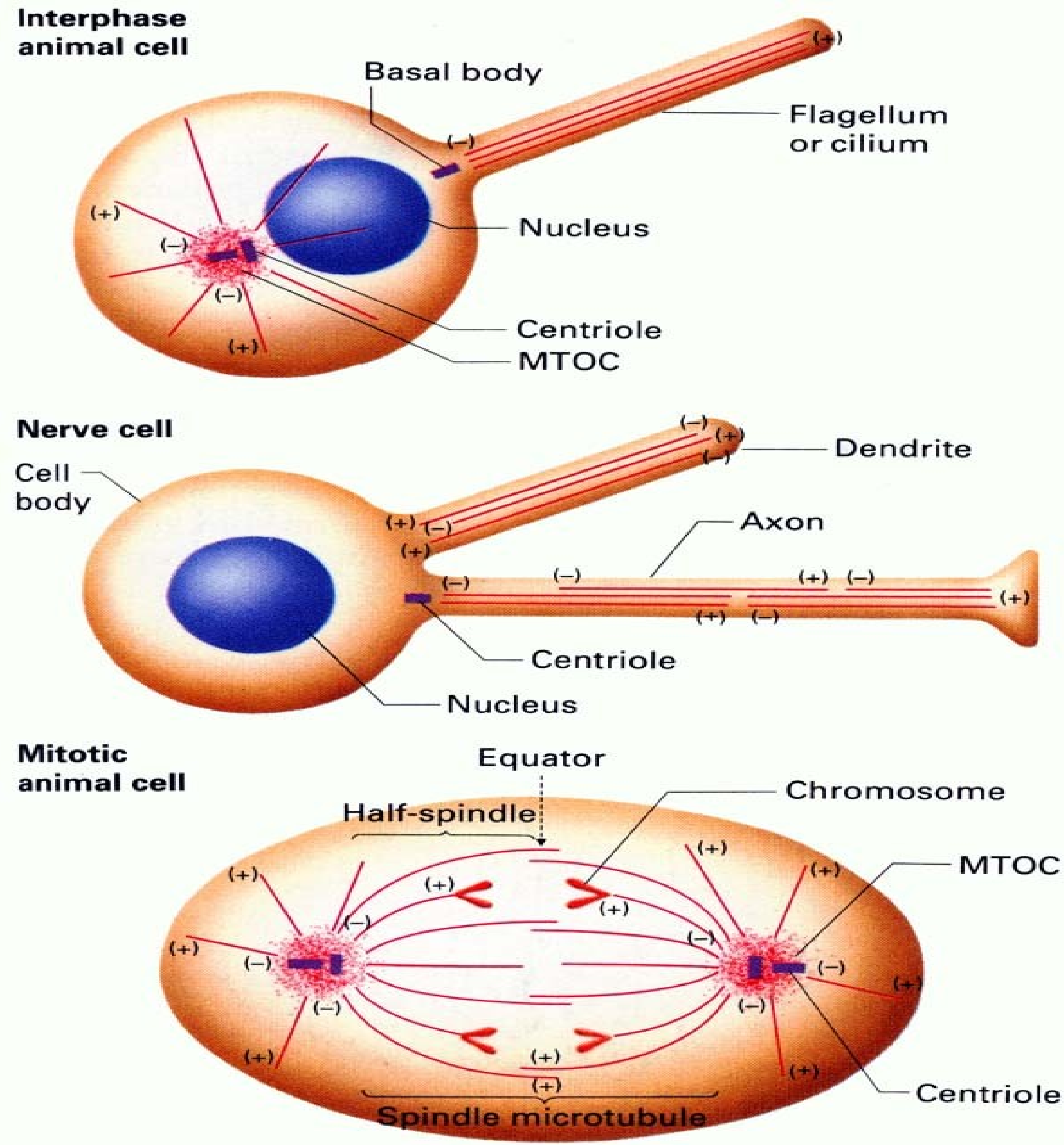

Microvillus
Cell membrane
Microfilaments
Terminal web
Intermediate filaments
Mitochondrion
Endoplasmic reticulum
Microtubule
Secretory vesicle

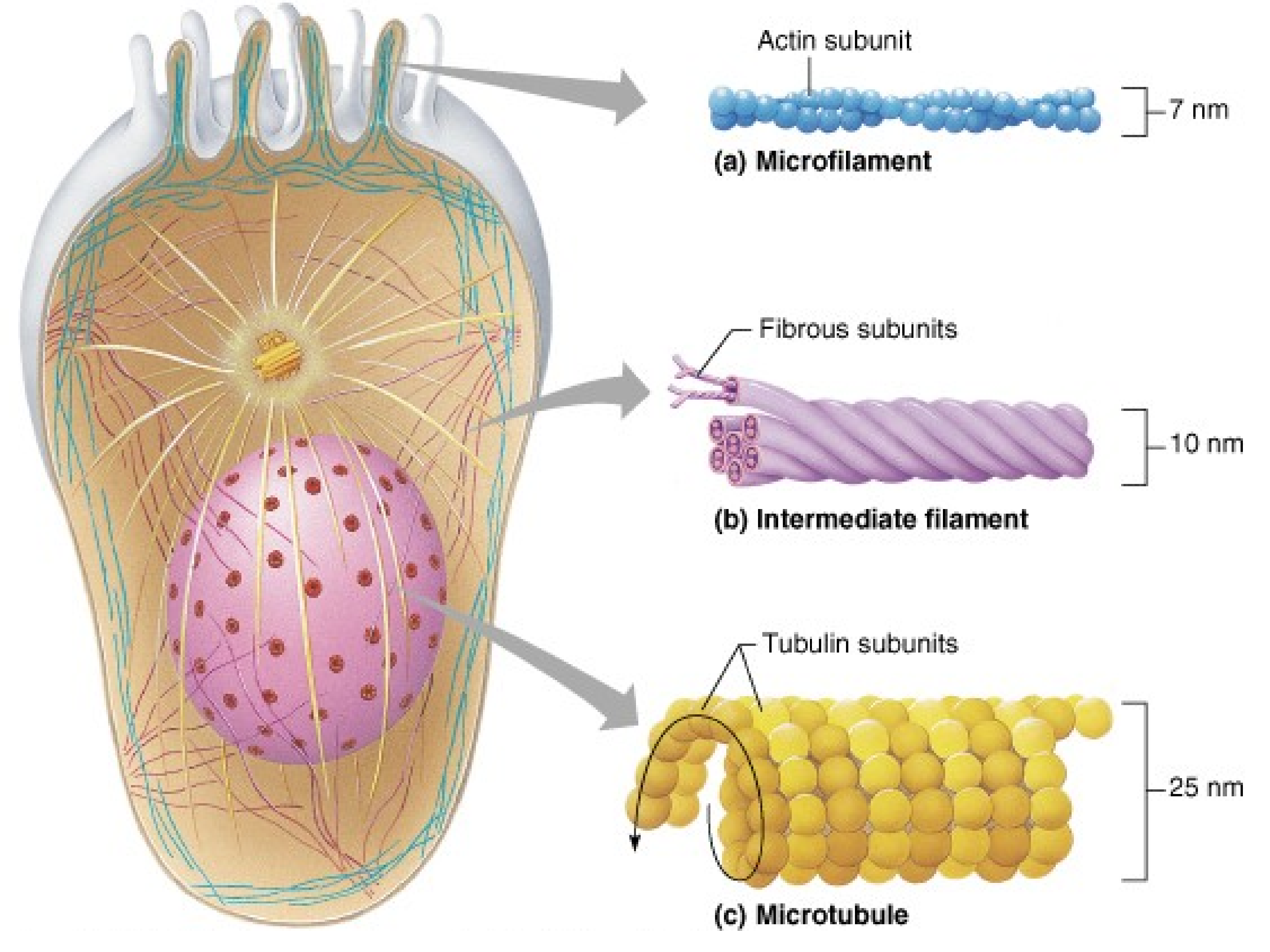
(a)



Red blood cell
Glycophorin
Band 3 protein
Ankyrin
Spectrin:
α-chain
β-chain
Band 4.1 protein
Actin


Cell anchored to
extracellular matrix
Cytosol
Actin
Cell membrane
Anchor proteins
Extracellular
matrix


Interphase animal cell
Basal body
Flagellum or cilium
Nucleus
Centriole
MTOC
(+)
(–)
Nerve cell
Cell body
Dendrite
Axon
Centriole
Nucleus
Mitotic animal cell
Equator
Chromosome
Half-spindle
MTOC
Centriole
Spindle microtubule

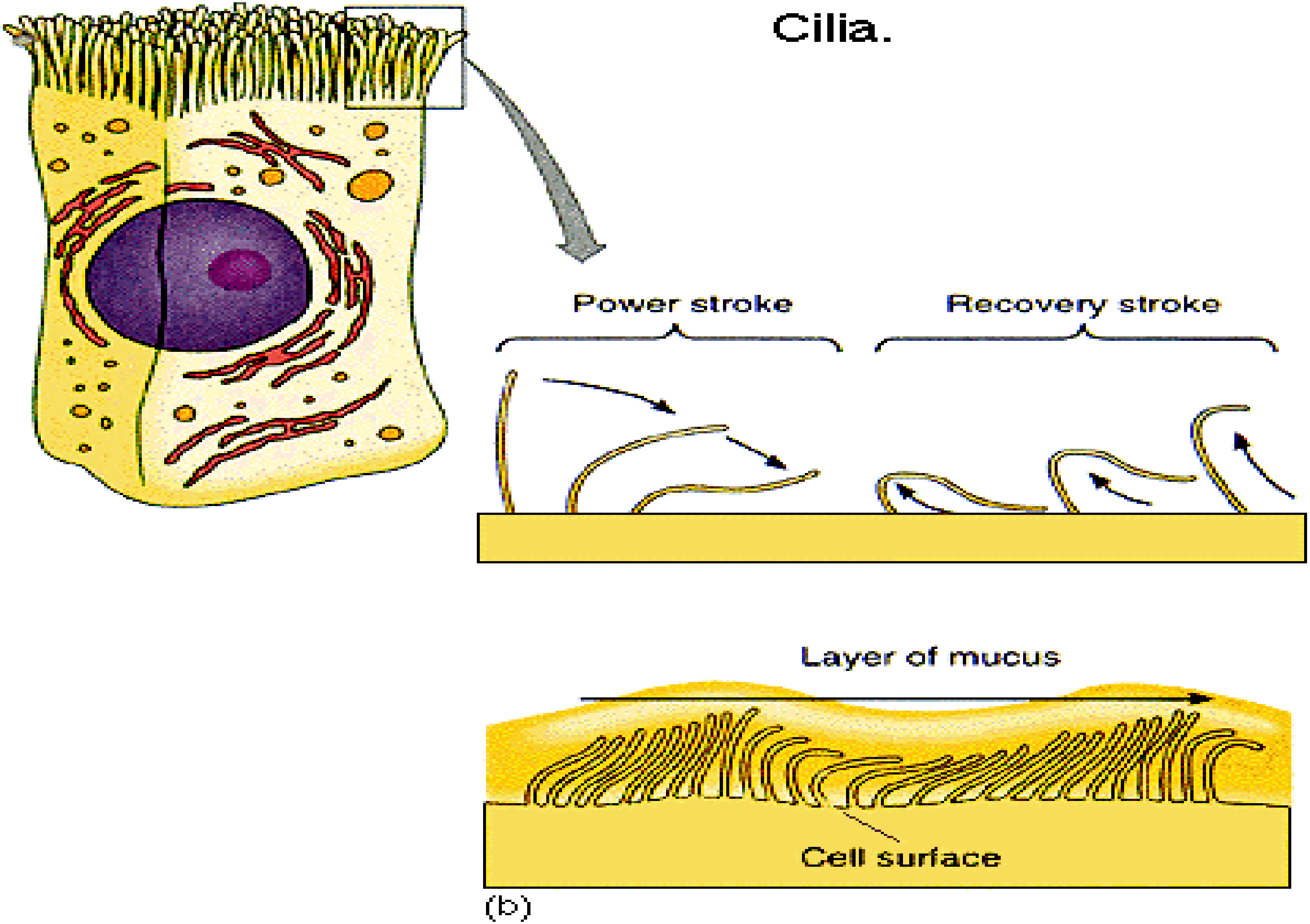


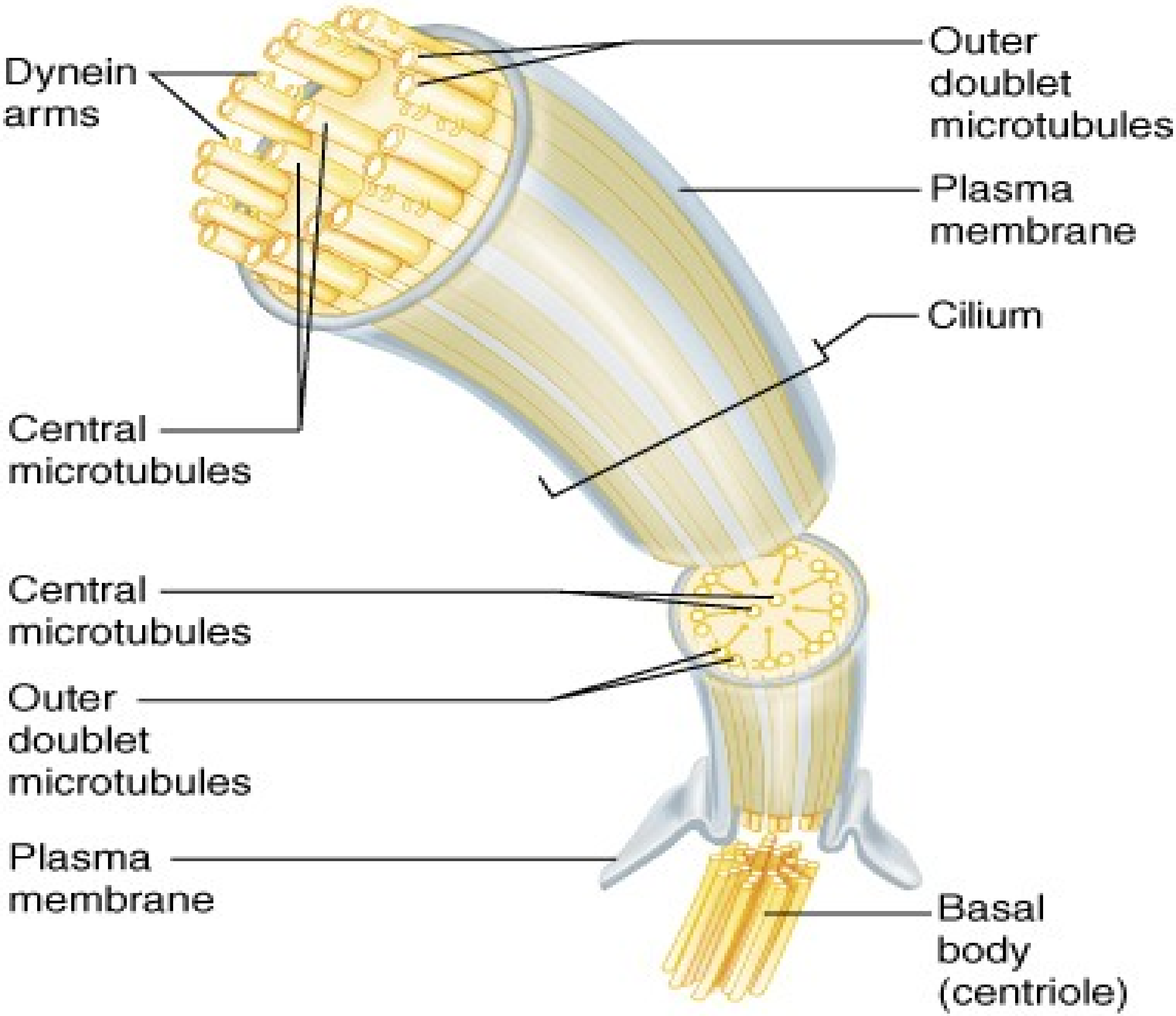
Actin subunit
7 nm
(a) Microfilament
Fibrous subunits
10 nm
(b) Intermediate filament
Tubulin subunits
25 nm
(c) Microtubule

Cilia and Flagella

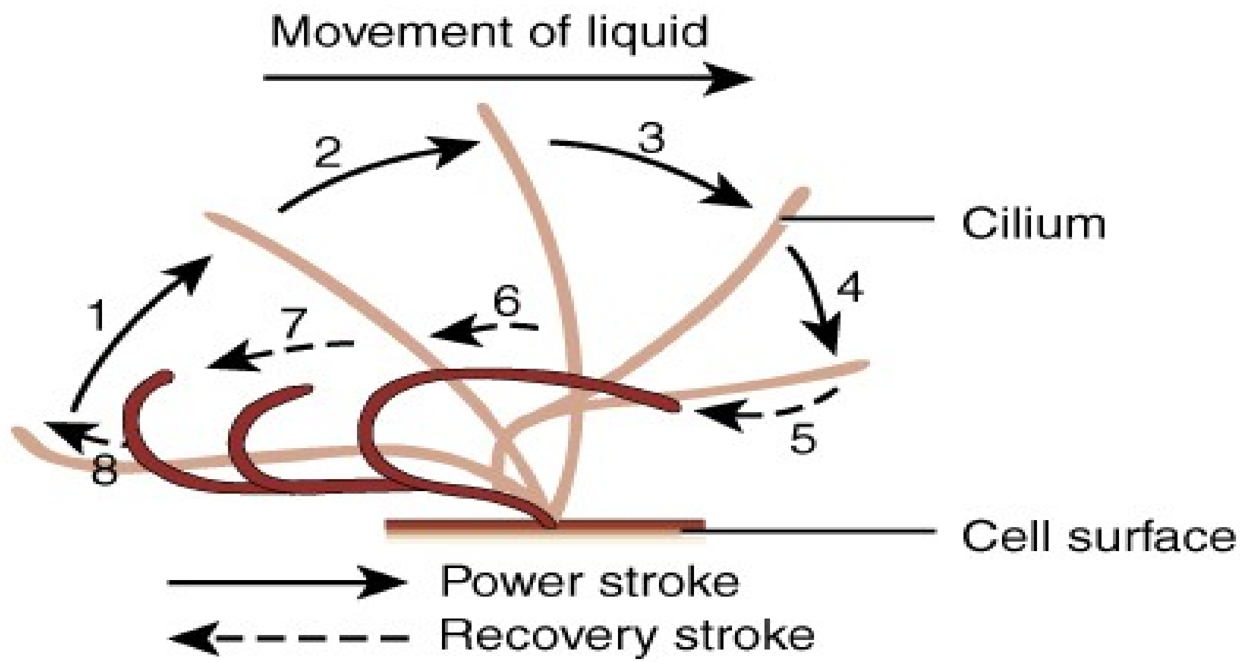
- *Cilia* are numerous, short, hairlike projections extending from the surface of a cell and functioning to move materials across the surface of the cell (Figs. 3.18a and b).
- *Flagella* are similar to cilia but are much longer; usually moving an entire cell. The only example of a flagellum in the human body is the sperm cell tail (Fig. 3.18c).

Cilia.

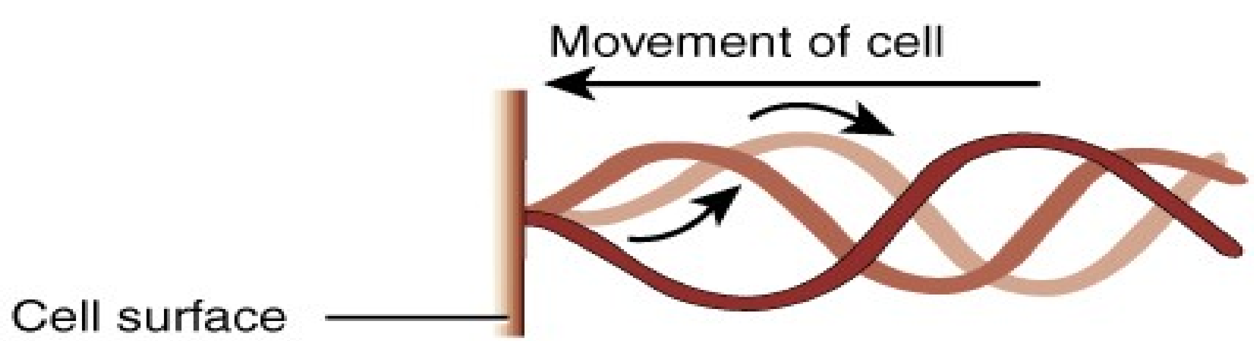



Dynein arms
Outer doublet microtubules
Plasma membrane
Cilium
Central microtubules
Central microtubules
Outer doublet microtubules
Plasma membrane
Basal body (centriole)

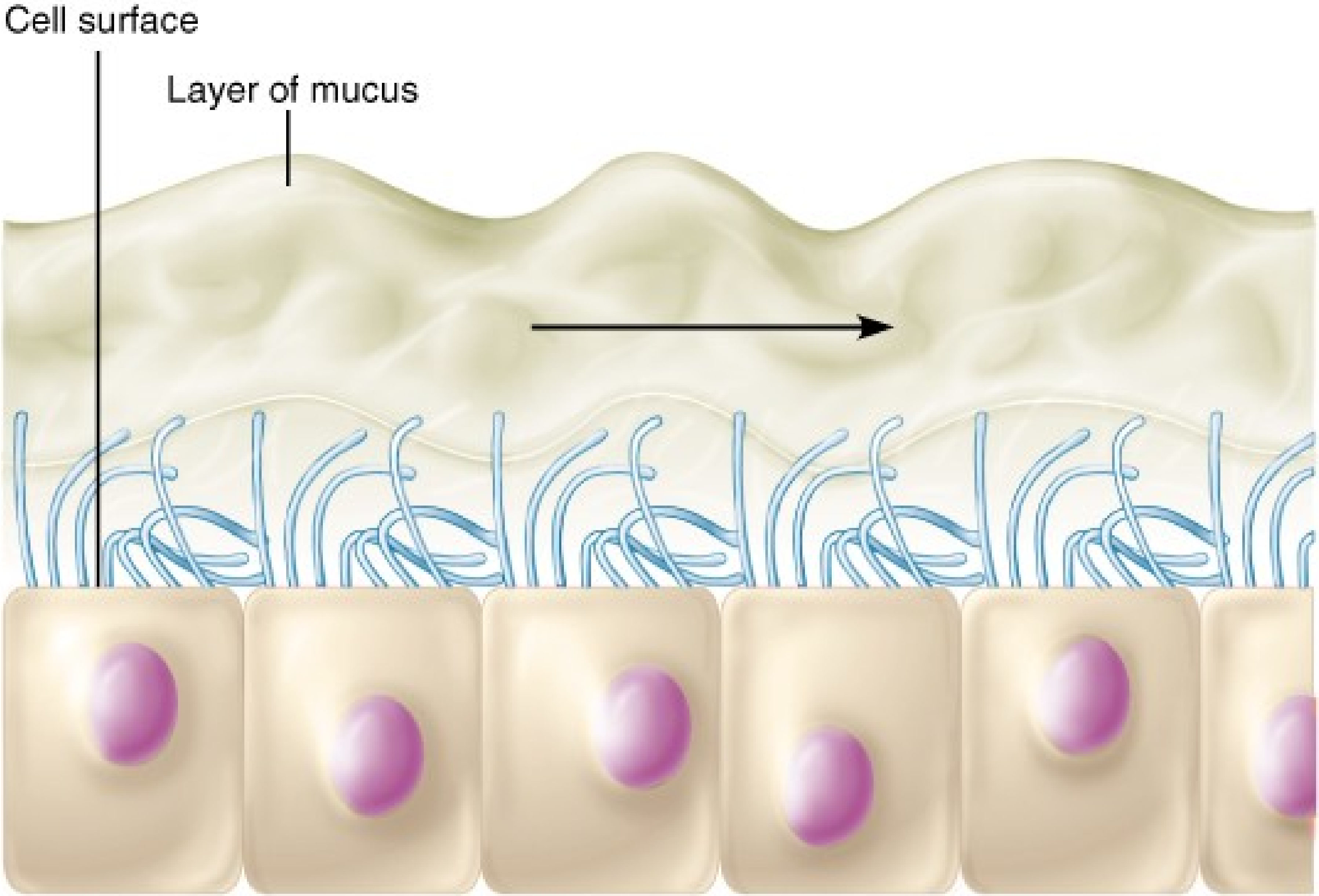
(a) Cilium



(b) Ciliary movement



(c) Flagellar movement



(c) Movement of mucus across cell surfaces

Ribosomes

- *Ribosomes* are tiny spheres consisting of ribosomal RNA and several ribosomal proteins; they occur free (singly or in clusters) or together with endoplasmic reticulum (Fig 3.19).
- Functionally, ribosomes are the sites of protein synthesis.

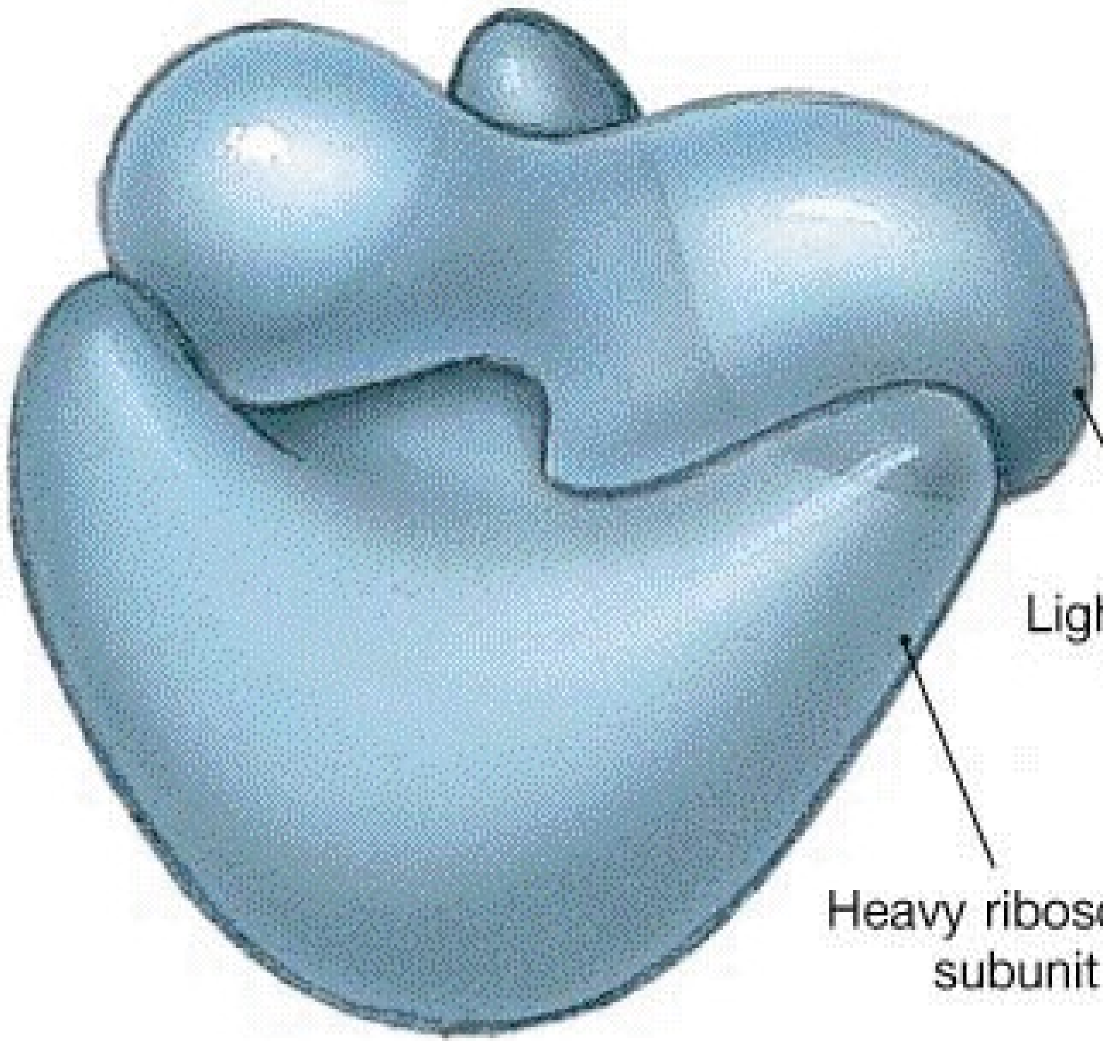
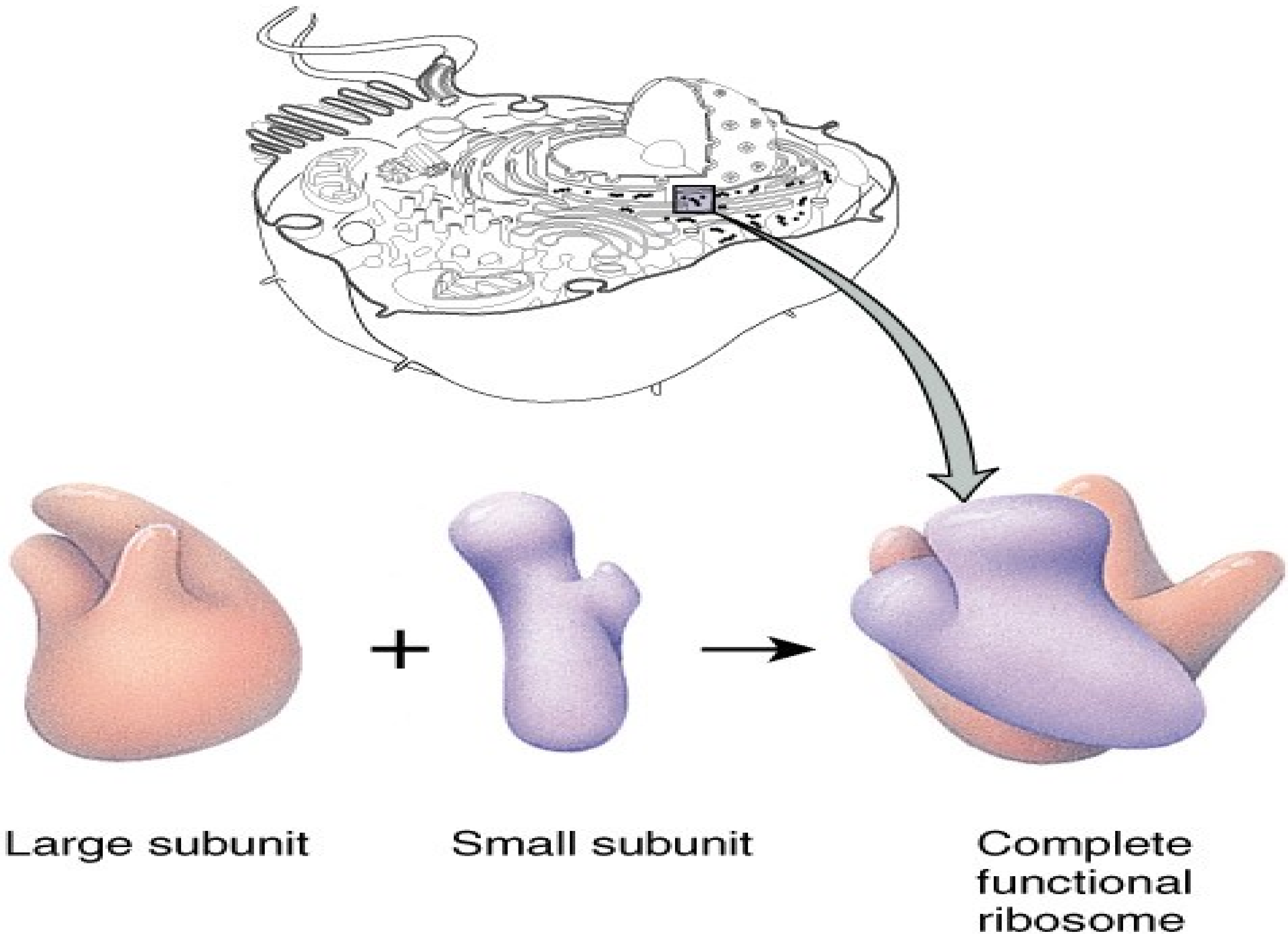


FIGURE 3-15 **Ribosomes.** A diagrammatic view of the structure of an intact ribosome. The subunits are separate unless the ribosome is engaged in protein synthesis.

Ribosome

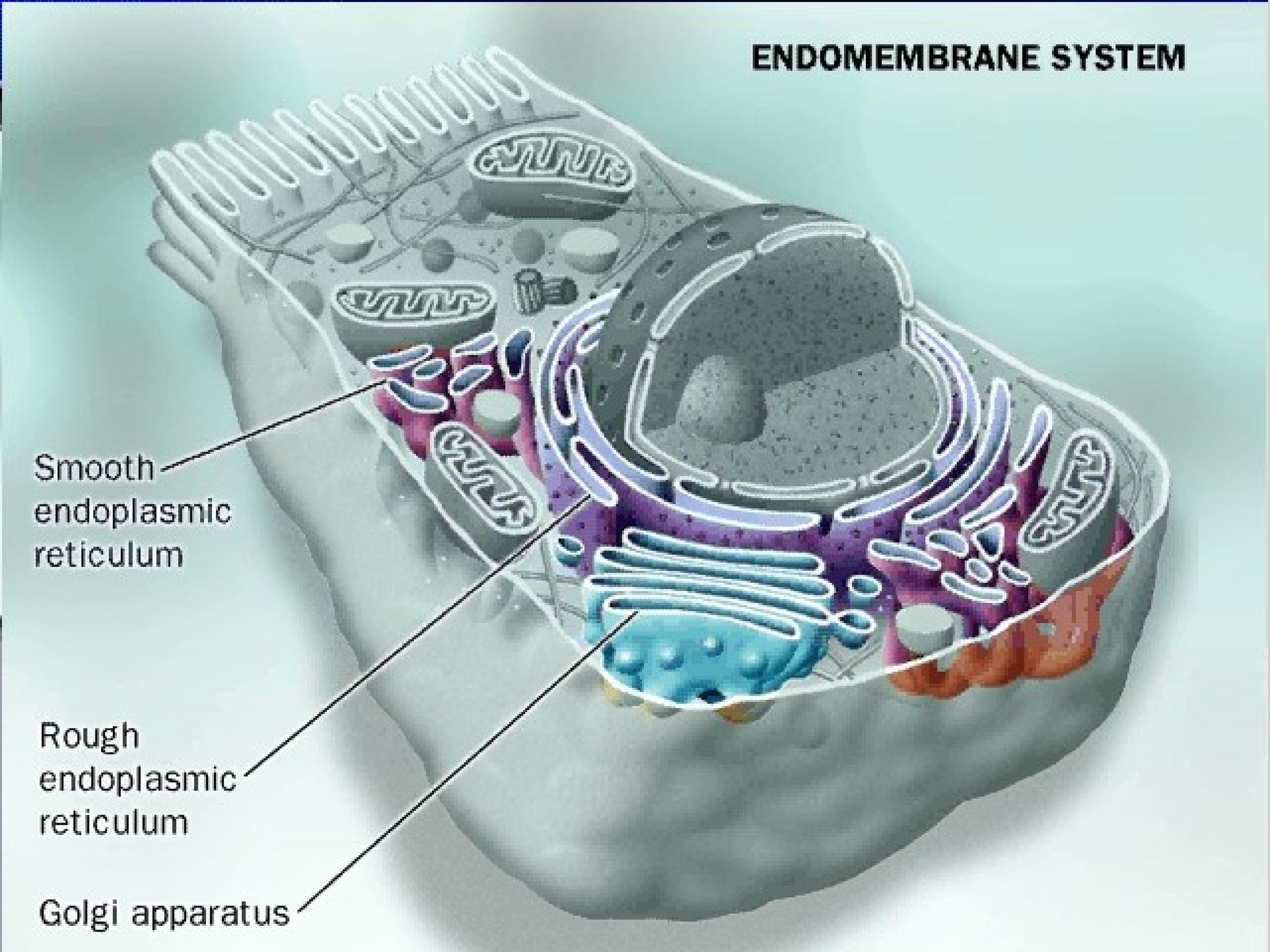
A ribosome is a tiny organelle composed of ribosomal RNAs and ribosomal proteins. It is not surrounded by a membrane. It is a "factory" for the synthesis of proteins, using information provided by mRNAs. A ribosome consists of two ribosomal subunits that combine only in the presence of mRNA and an appropriate charged transfer RNA. Both eukaryotic and prokaryotic cells contain ribosomes.



Details of ribosomal subunits

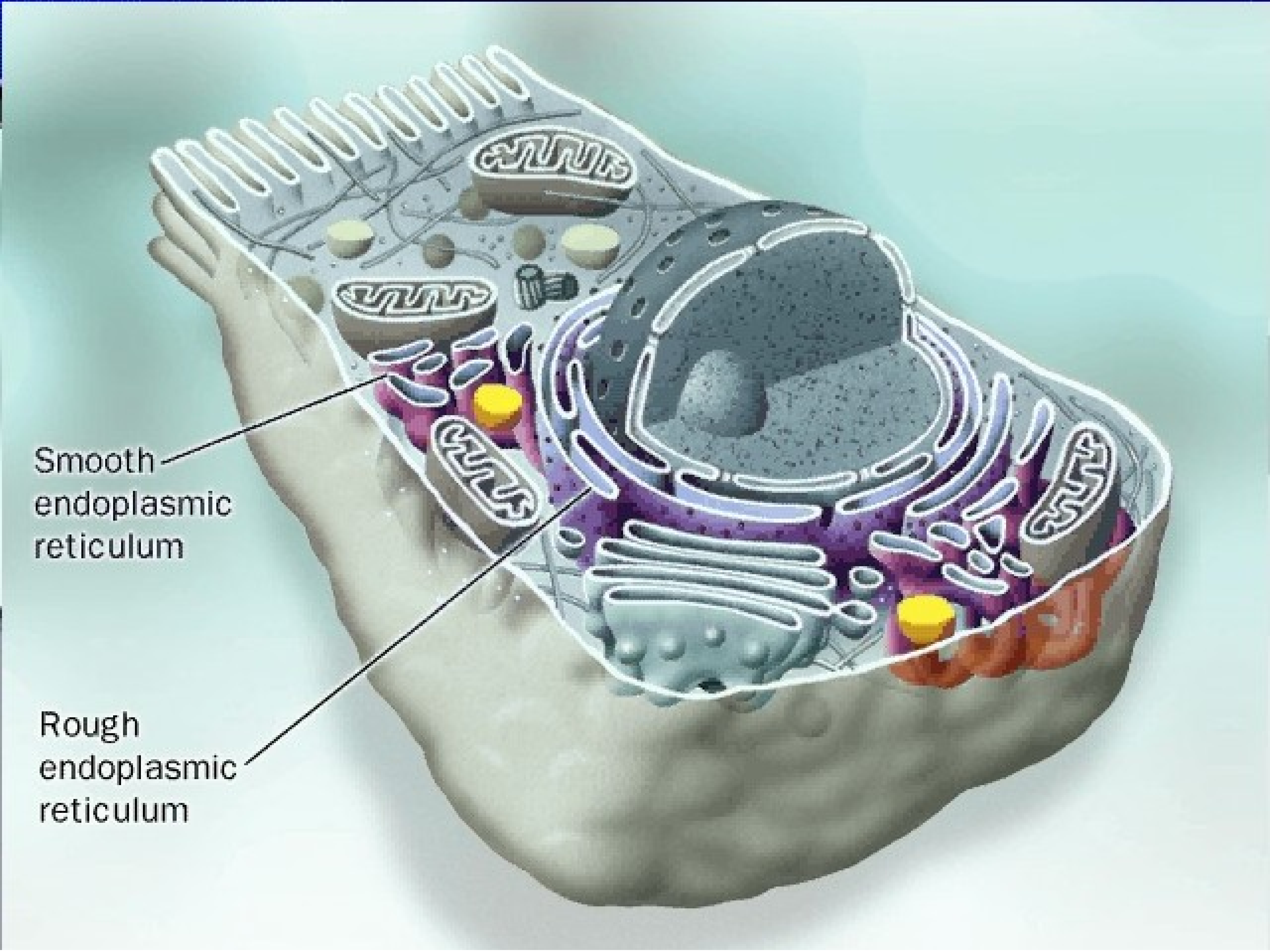
Endomembrane system

The endomembrane system is an extensive set of closely interrelated membranes inside a eukaryotic cell. The components of the endomembrane system exchange materials by means of vesicles. The chief components of the endomembrane system are the endoplasmic reticulum and the Golgi apparatus.

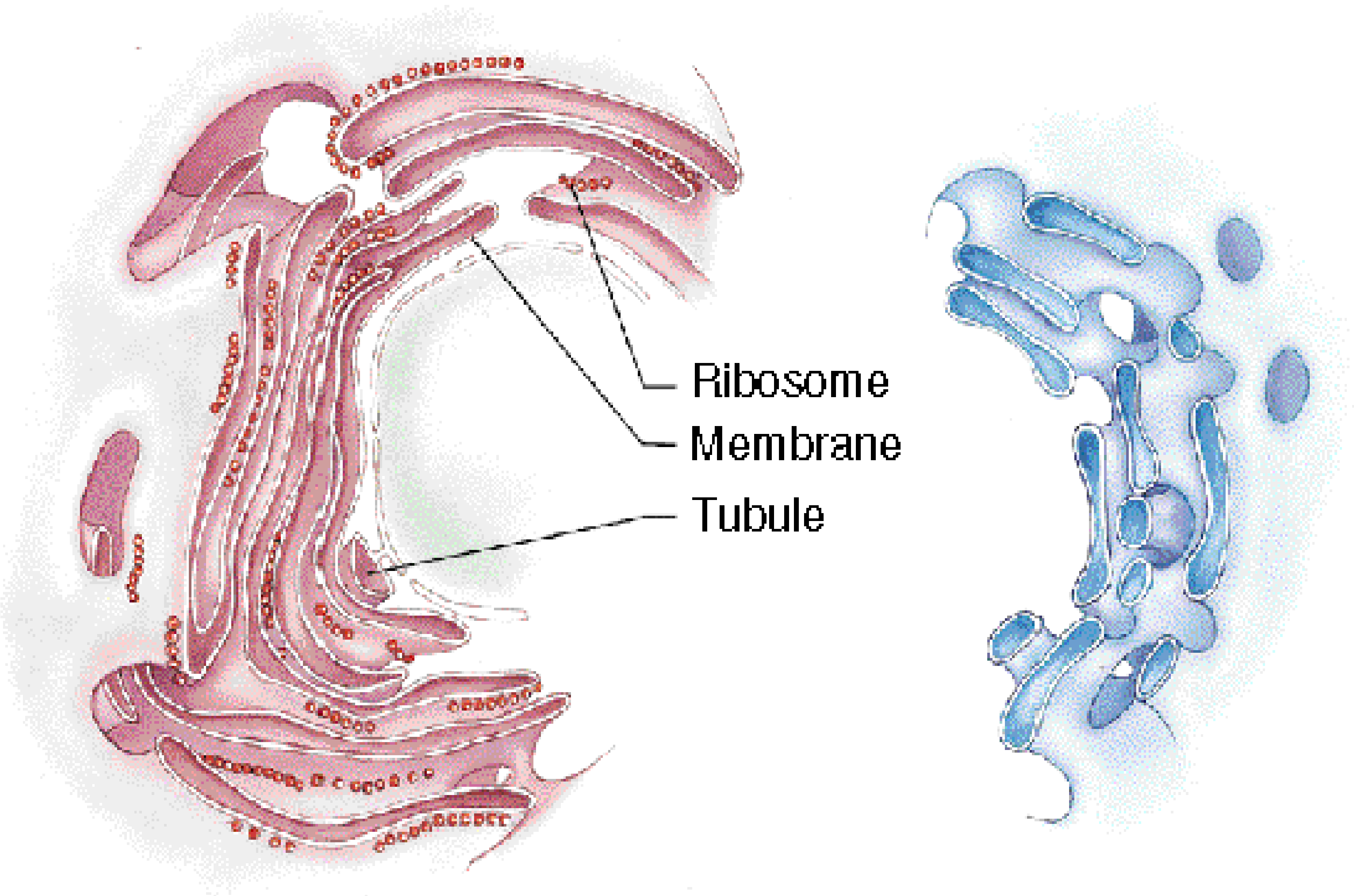

ENDOMEMBRANE SYSTEM
Smooth endoplasmic reticulum
Rough endoplasmic reticulum
Golgi apparatus

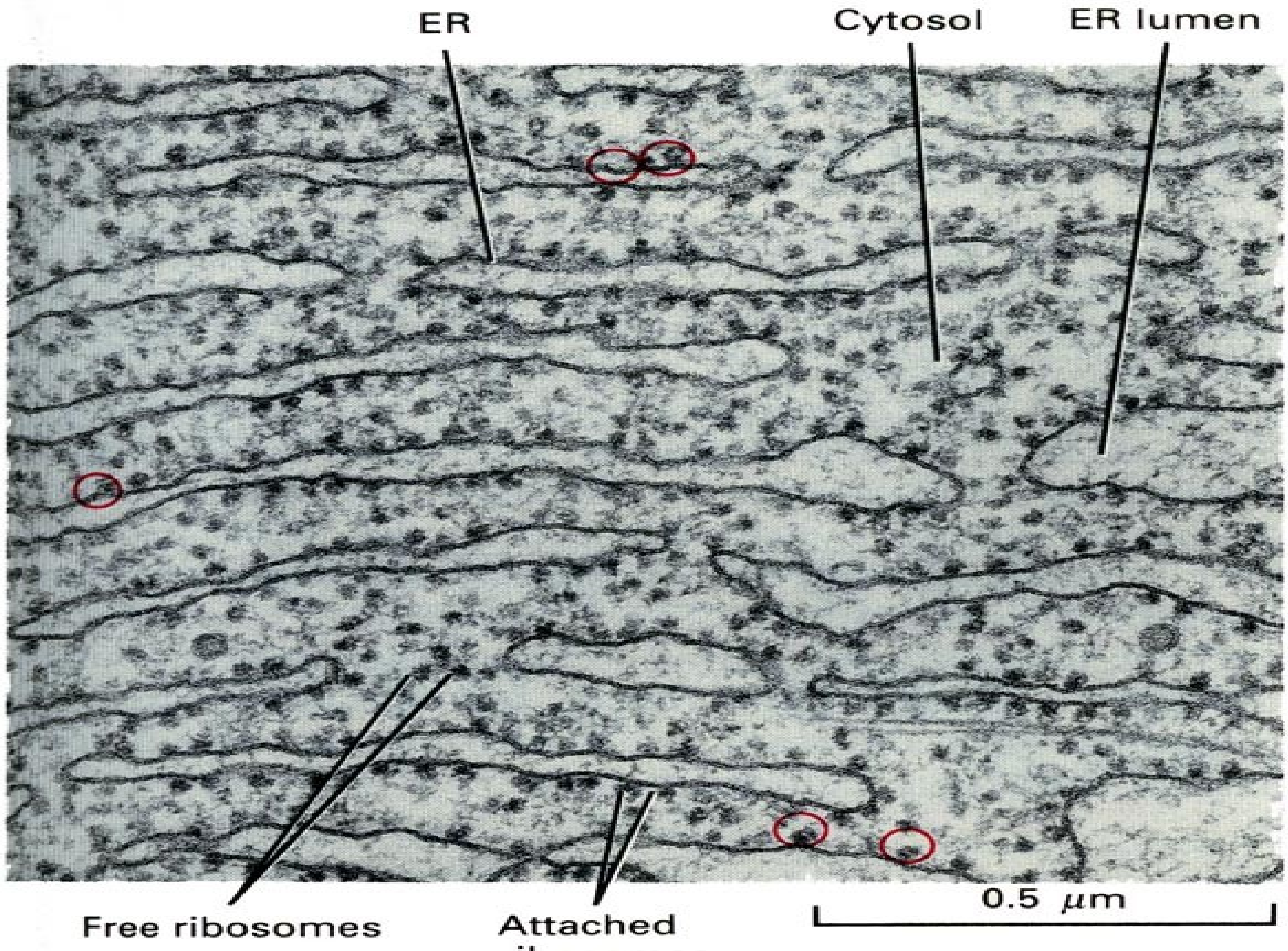
Endoplasmic Reticulum

- The *endoplasmic reticulum* (ER) is a network of membranes that form flattened sacs or tubules called cisterns (Fig. 3.20).
  - *Rough ER* is continuous with the nuclear membrane and has its outer surface studded with **ribosomes**.
  - *Smooth ER* extends from the rough ER to form a network of membrane tubules but does not contain ribosomes on its membrane surface.


Smooth endoplasmic reticulum
Rough endoplasmic reticulum

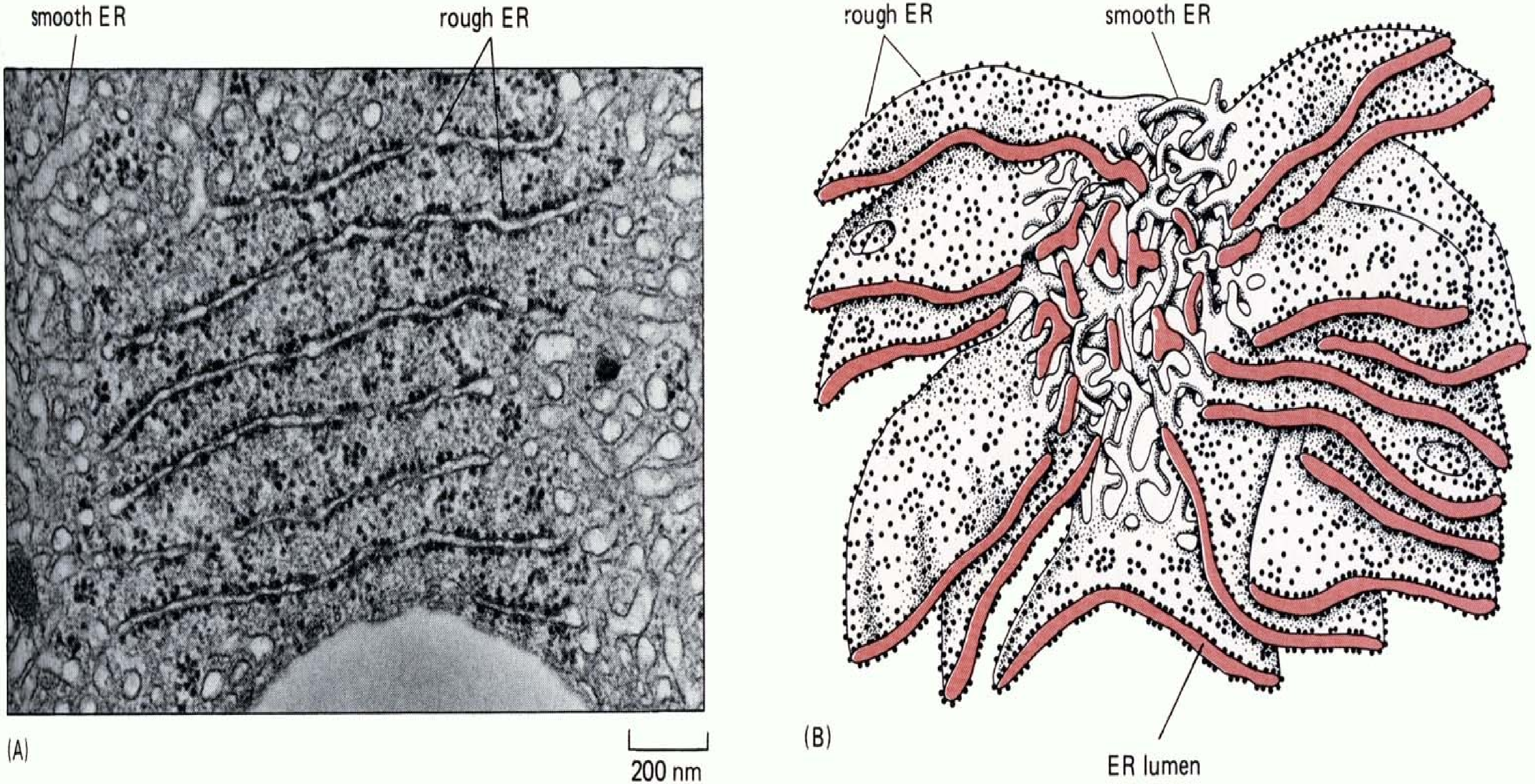
Endoplasmic Reticulum. Figure 3.11b,c

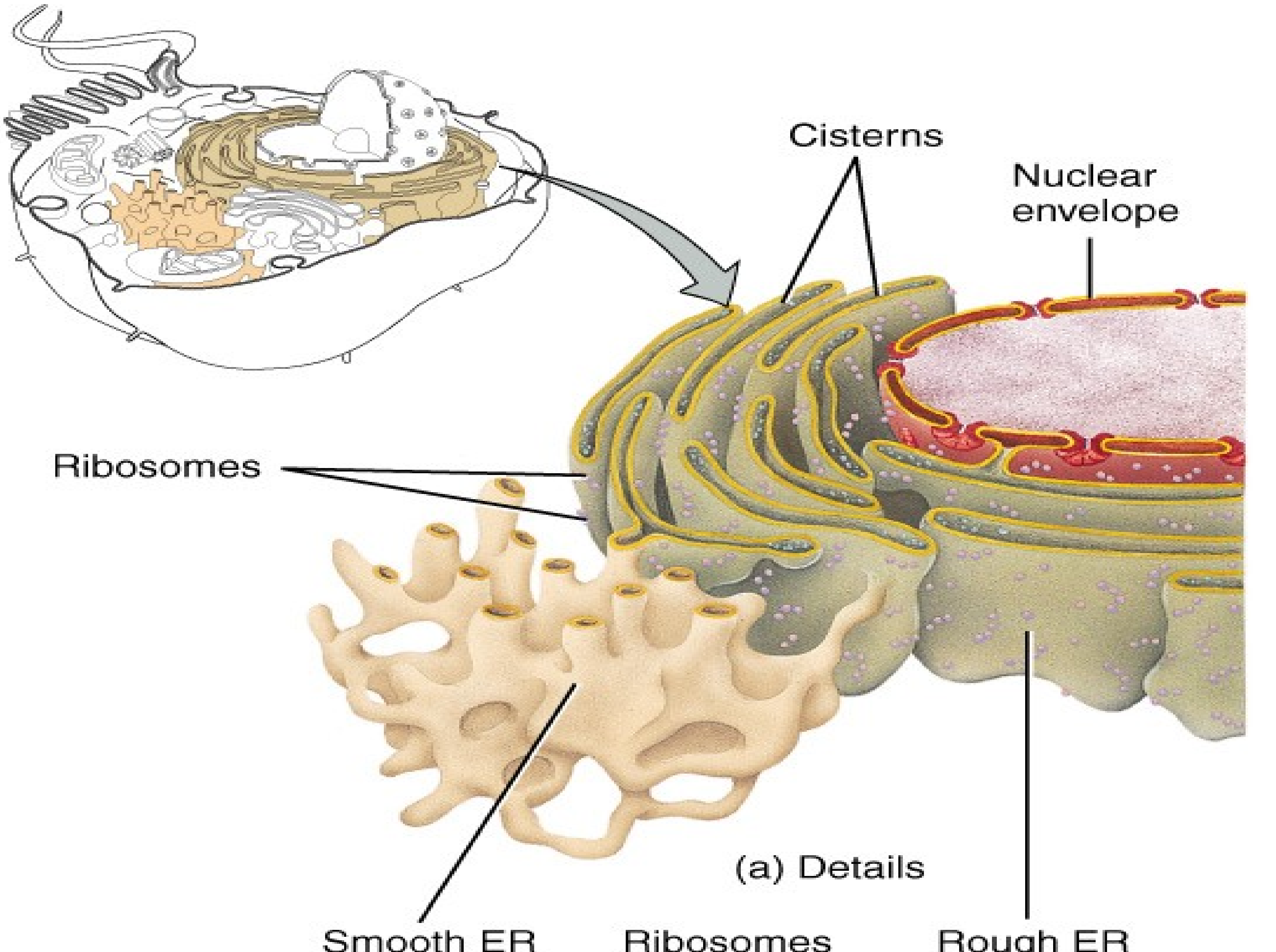


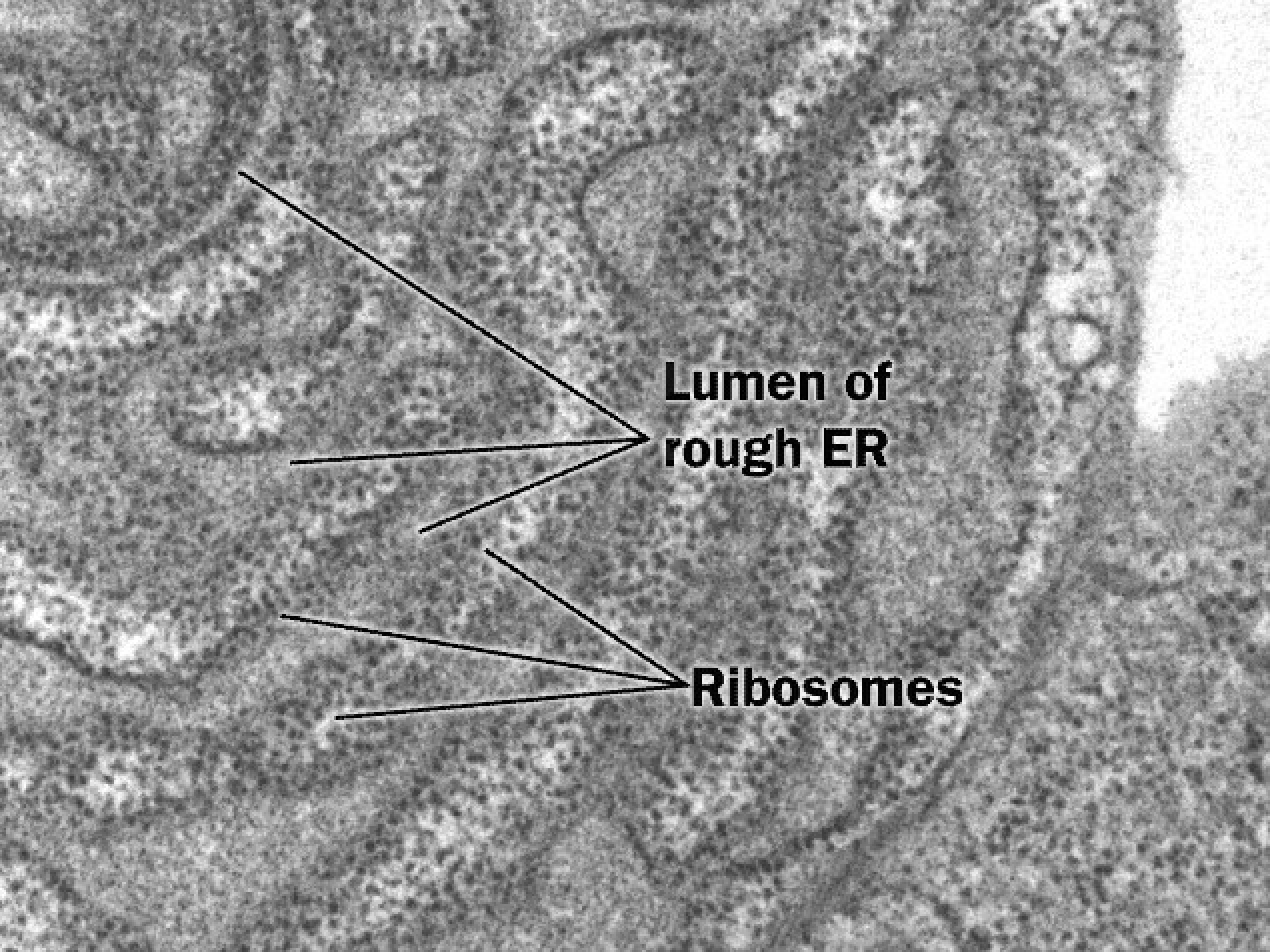

ER
Cytosol
ER lumen
Free ribosomes
Attached
ribosomes
0.5 μm

Endoplasmic Reticulum

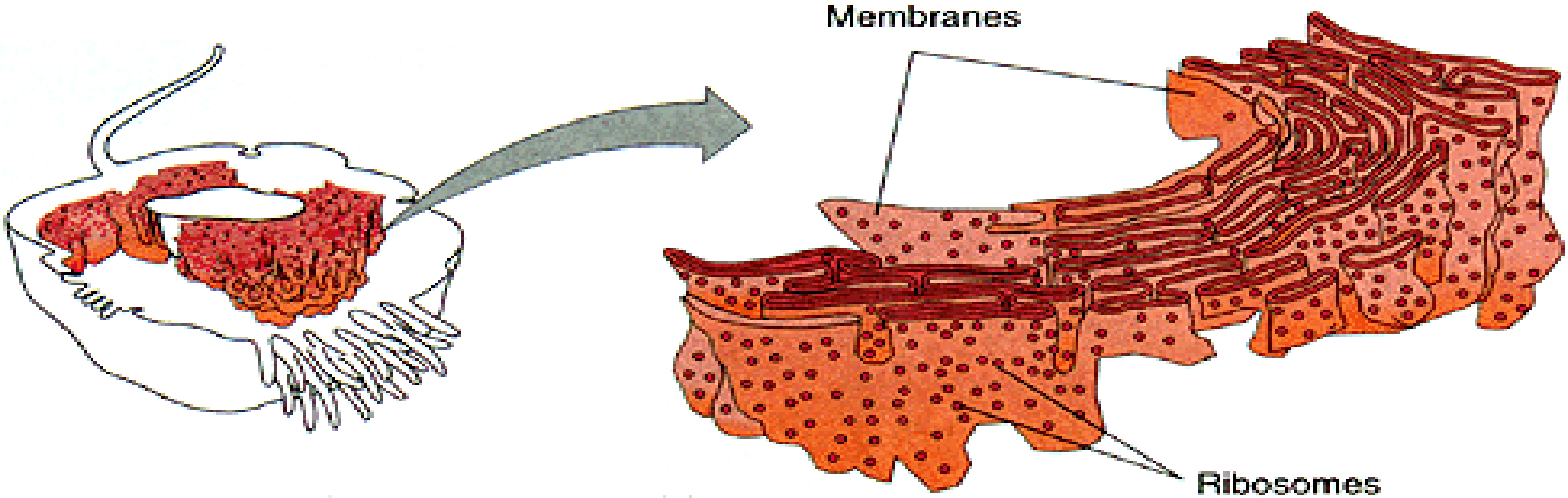
- The ER transports substances, stores newly synthesized molecules, synthesizes and packages molecules, detoxifies chemicals, and releases calcium ions involved in muscle contraction.


smooth ER
rough ER
(A)
200 nm
rough ER
smooth ER
(B)
ER lumen

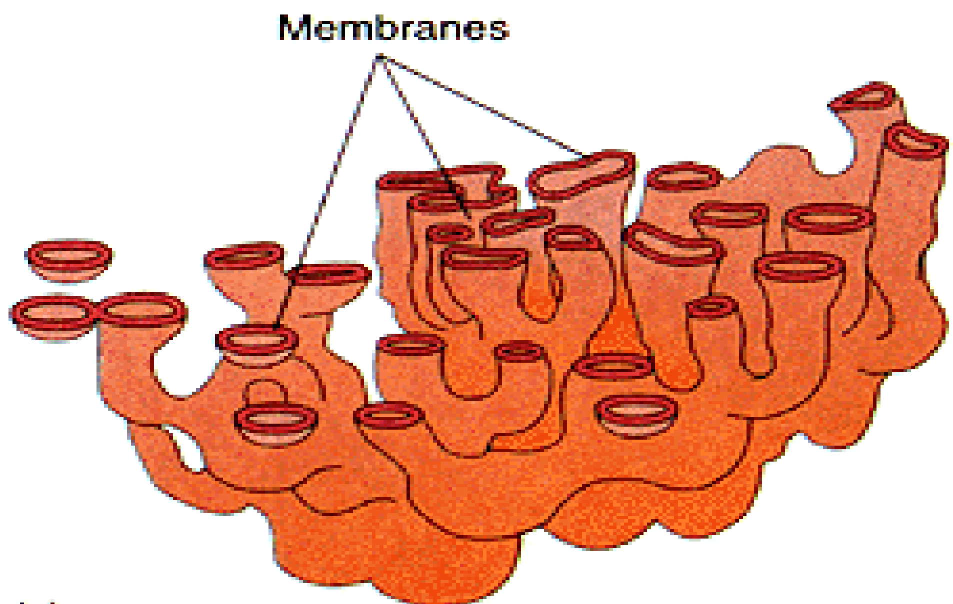

Cisterns
Nuclear
envelope
Ribosomes
(a) Details
Smooth ER
Ribosomes
Rough ER


Lumen of
rough ER
Ribosomes

Endoplasmic Reticulum.



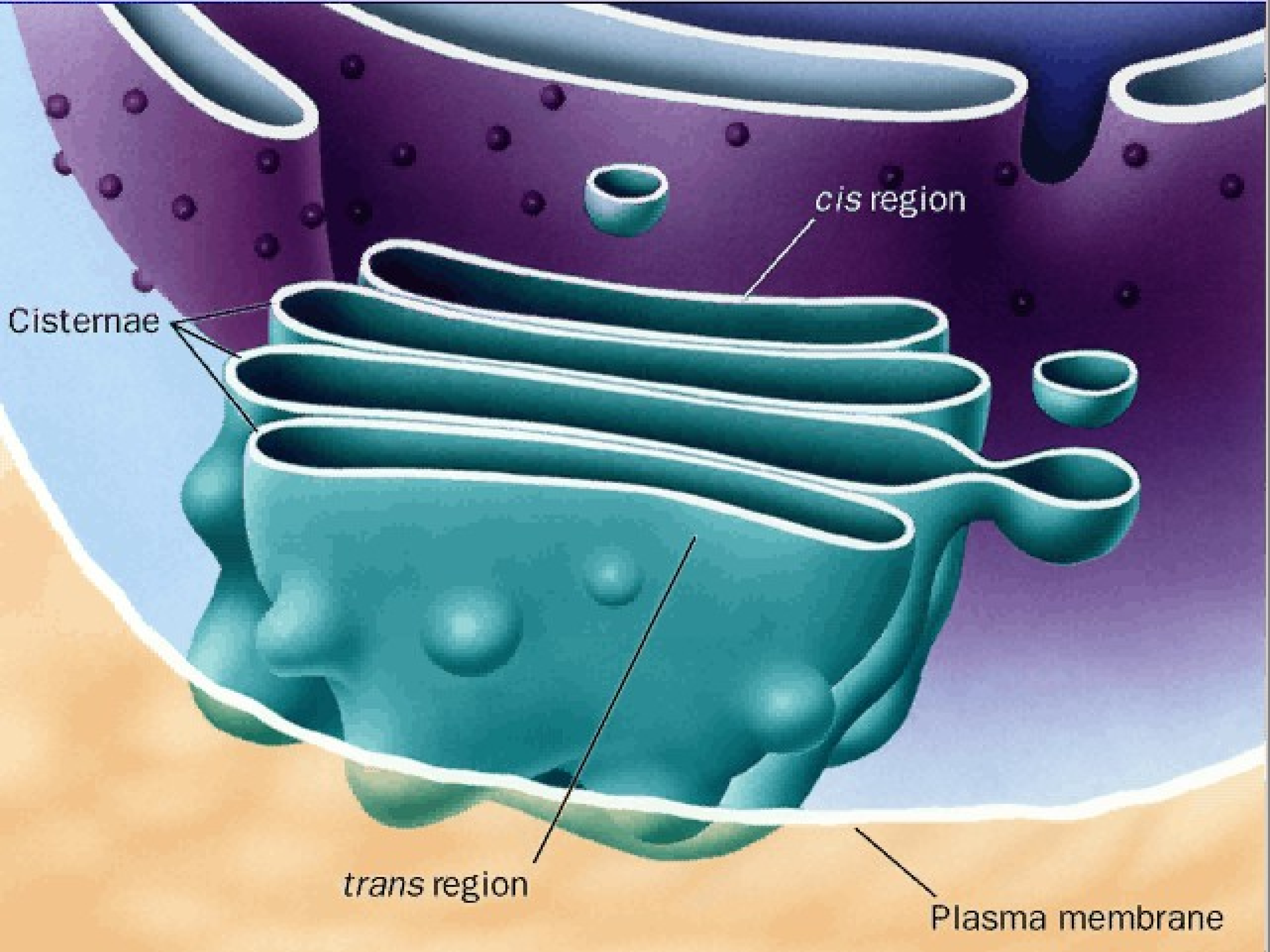
(b)



(c)

Golgi Complex

- The *Golgi complex* consists of four to six stacked, flattened membranous sacs (cisterns) referred to as cis, medial, and trans (Fig. 3.21).
- The principal function of the Golgi complex is to process, sort, and deliver proteins and lipids to the plasma membrane, lysosomes, and secretory vesicles (Fig. 3.22).

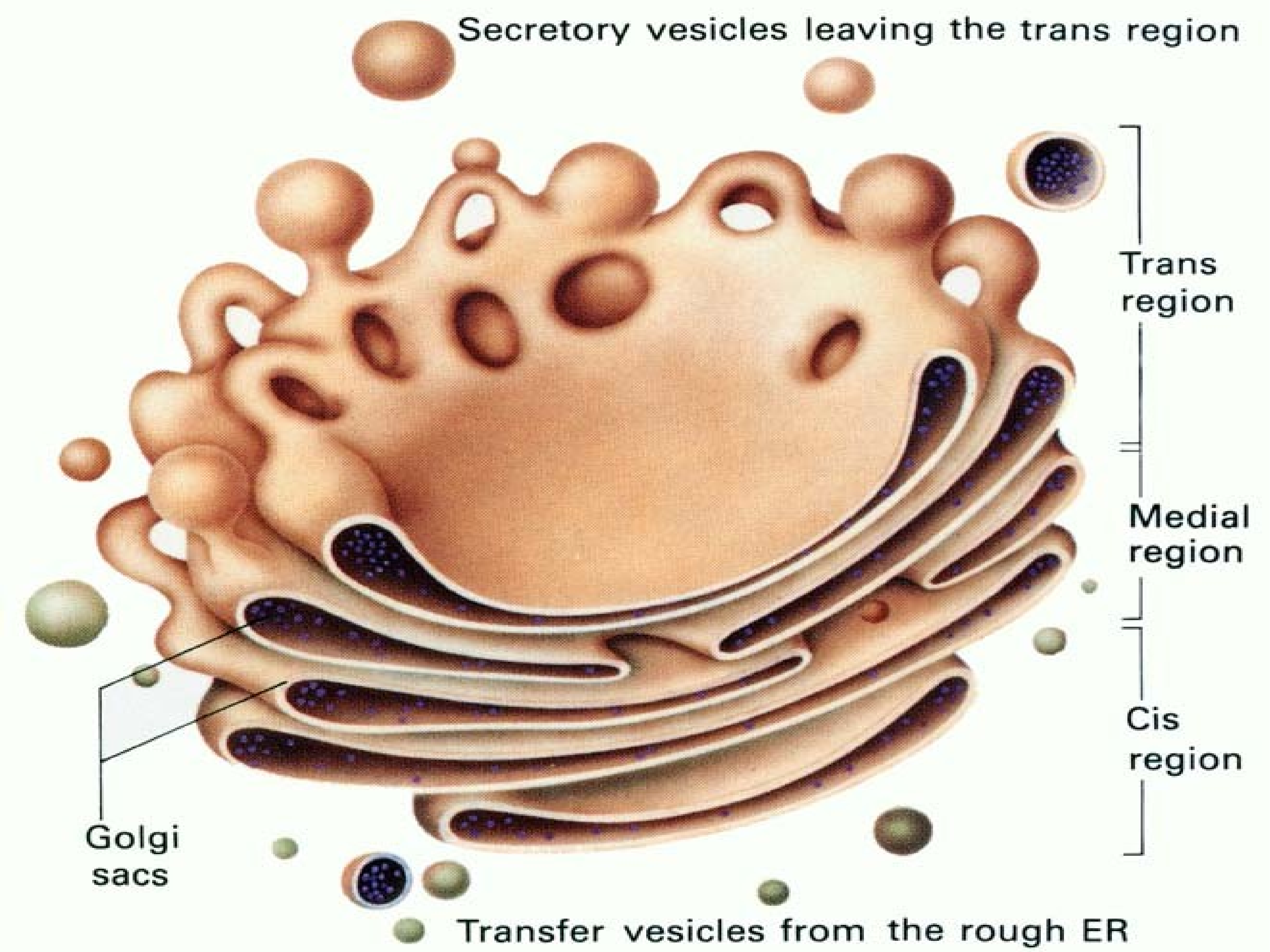

cis region
Cisternae
trans region
Plasma membrane

Golgi apparatus

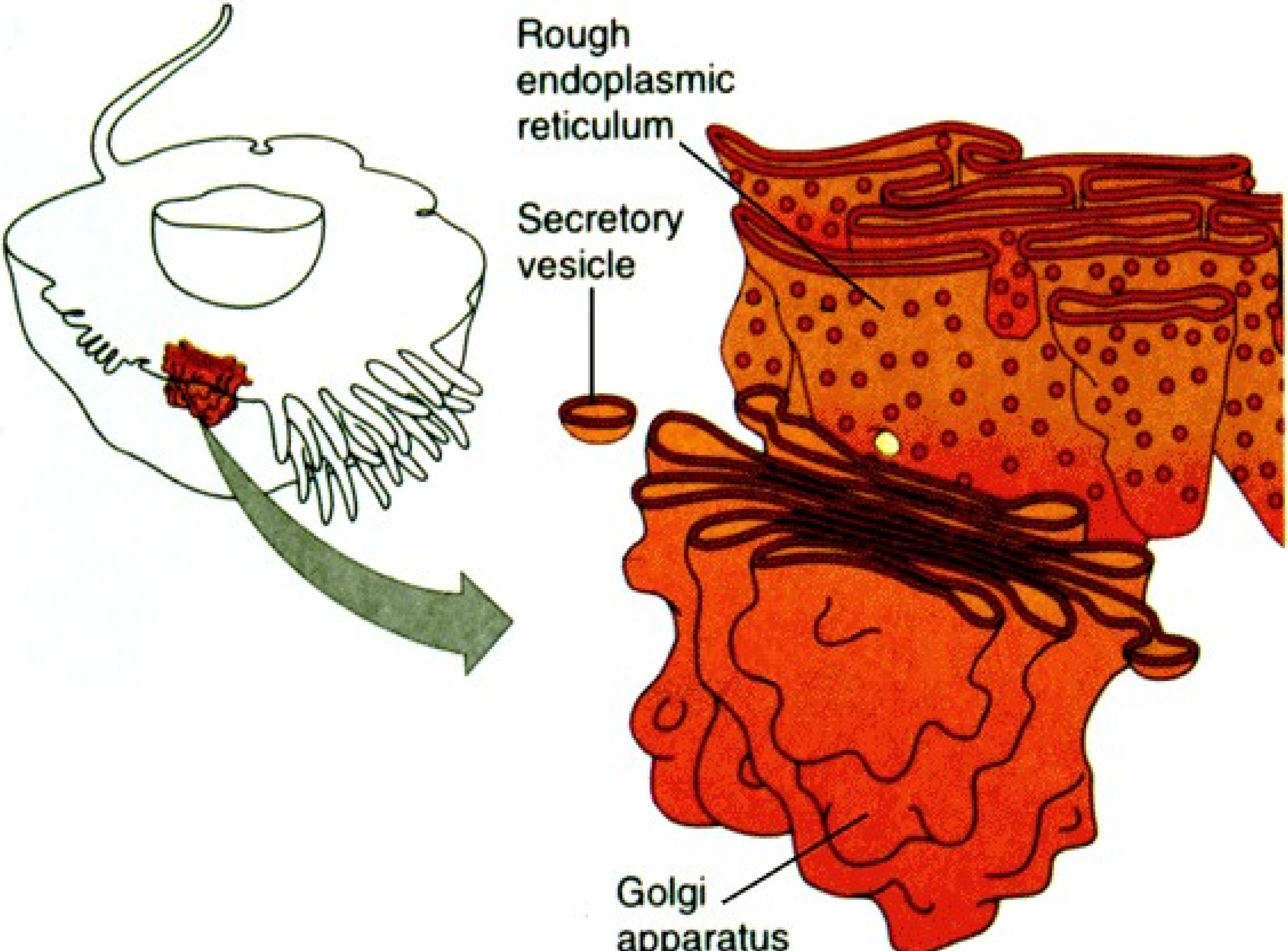
The Golgi apparatus is a packaging and processing station for molecular traffic among parts of the cell. It is a system of folded membranes, arranged like stacks of pocket bread (pita), in eukaryotic cells. In a Golgi apparatus, there are important differences between the *cis* and *trans* regions; materials are processed through the apparatus from the *cis* region to the *trans* region.

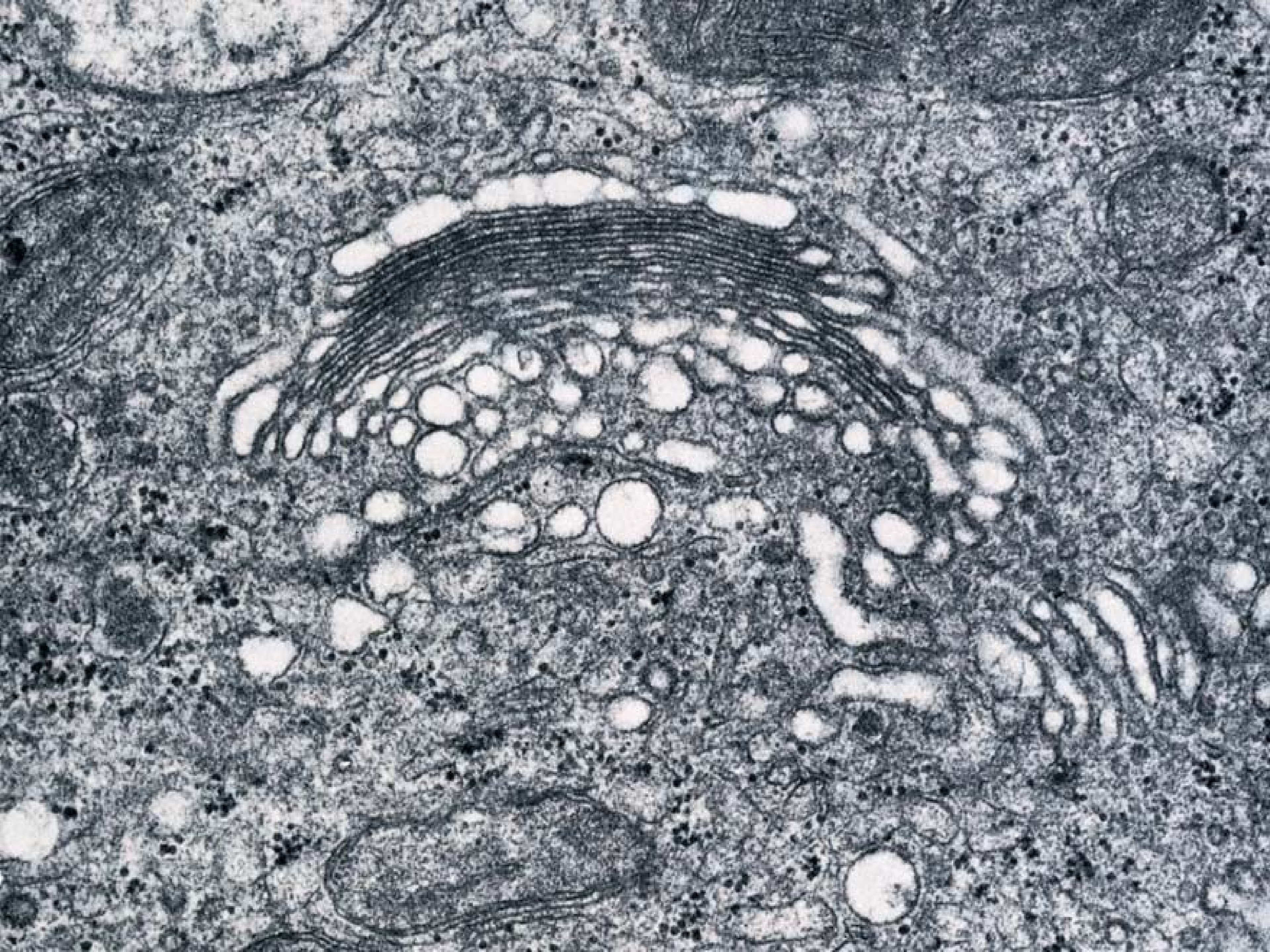
cis Region

The *cis* region of a Golgi apparatus lies toward the nucleus and away from the plasma membrane. Vesicles deliver proteins and other materials from the endoplasmic reticulum to the cisternae of the *cis* region of the Golgi apparatus. Vesicles break away from these cisternae, transporting materials toward the *trans* region of the Golgi apparatus. The face of the *cis* region that faces the endoplasmic reticulum was formerly called the "forming face" of the Golgi apparatus.

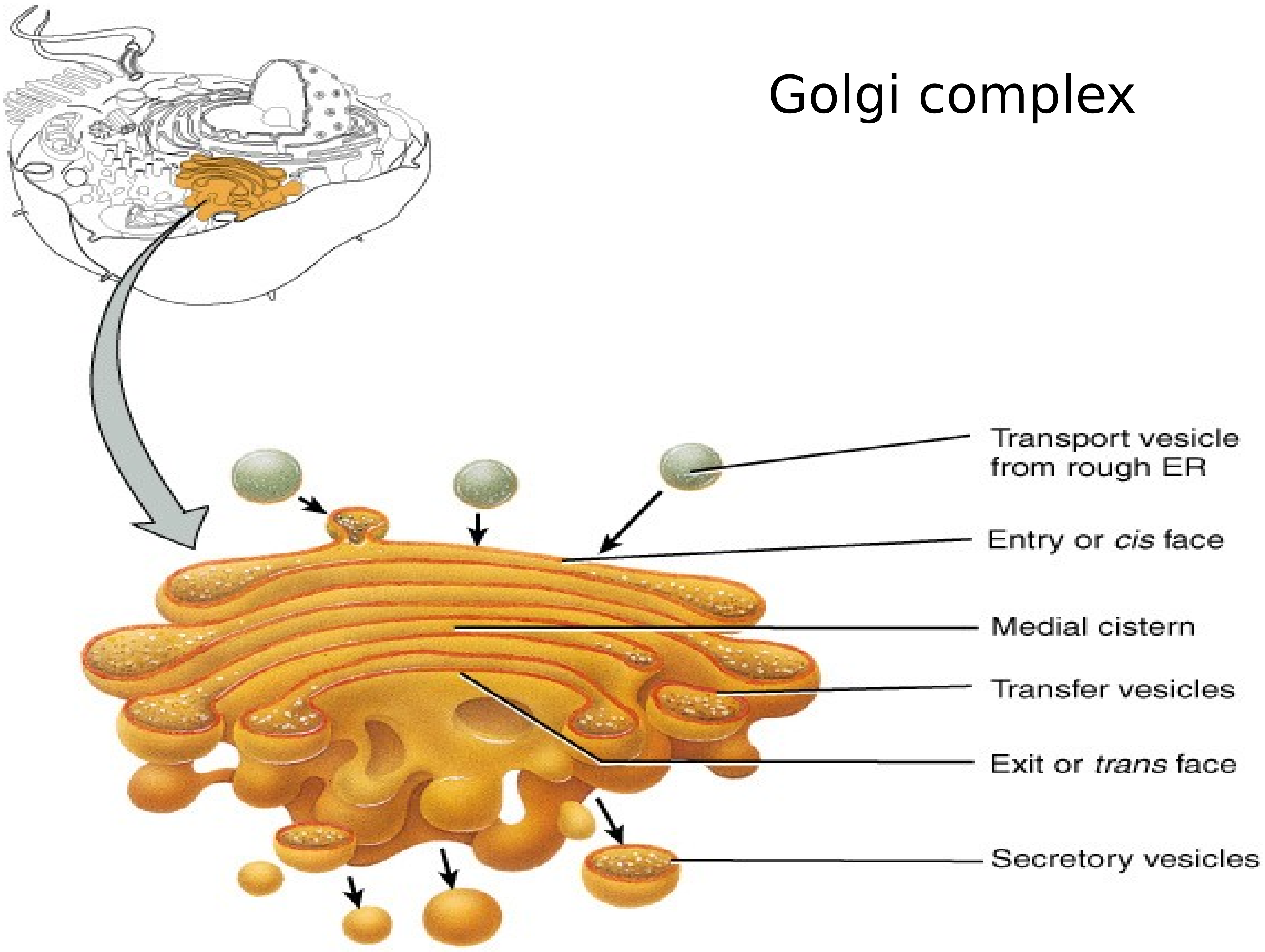

Secretory vesicles leaving the trans region
Trans region
Medial region
Cis region
Golgi sacs
Transfer vesicles from the rough ER

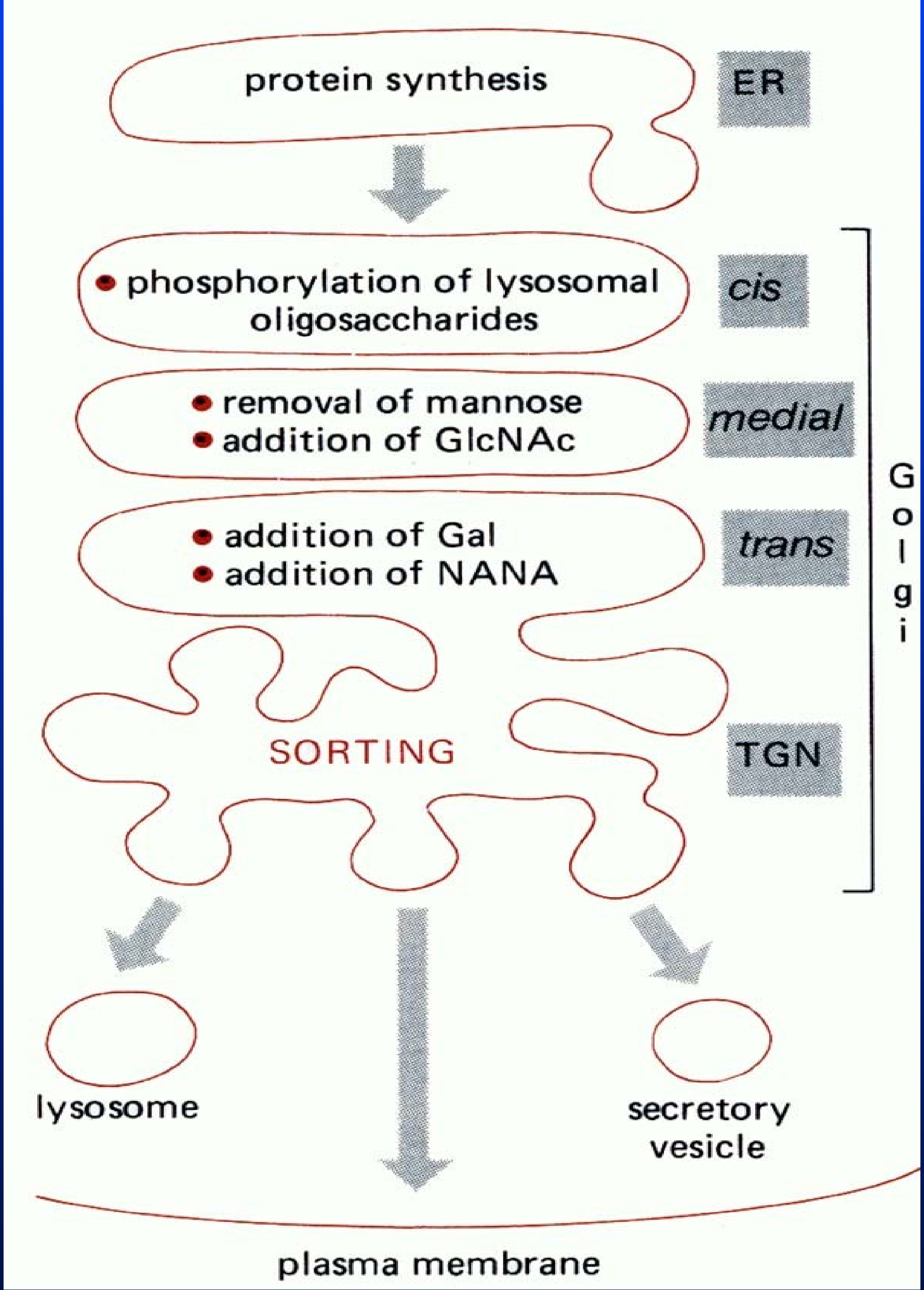
Golgi Apparatus.

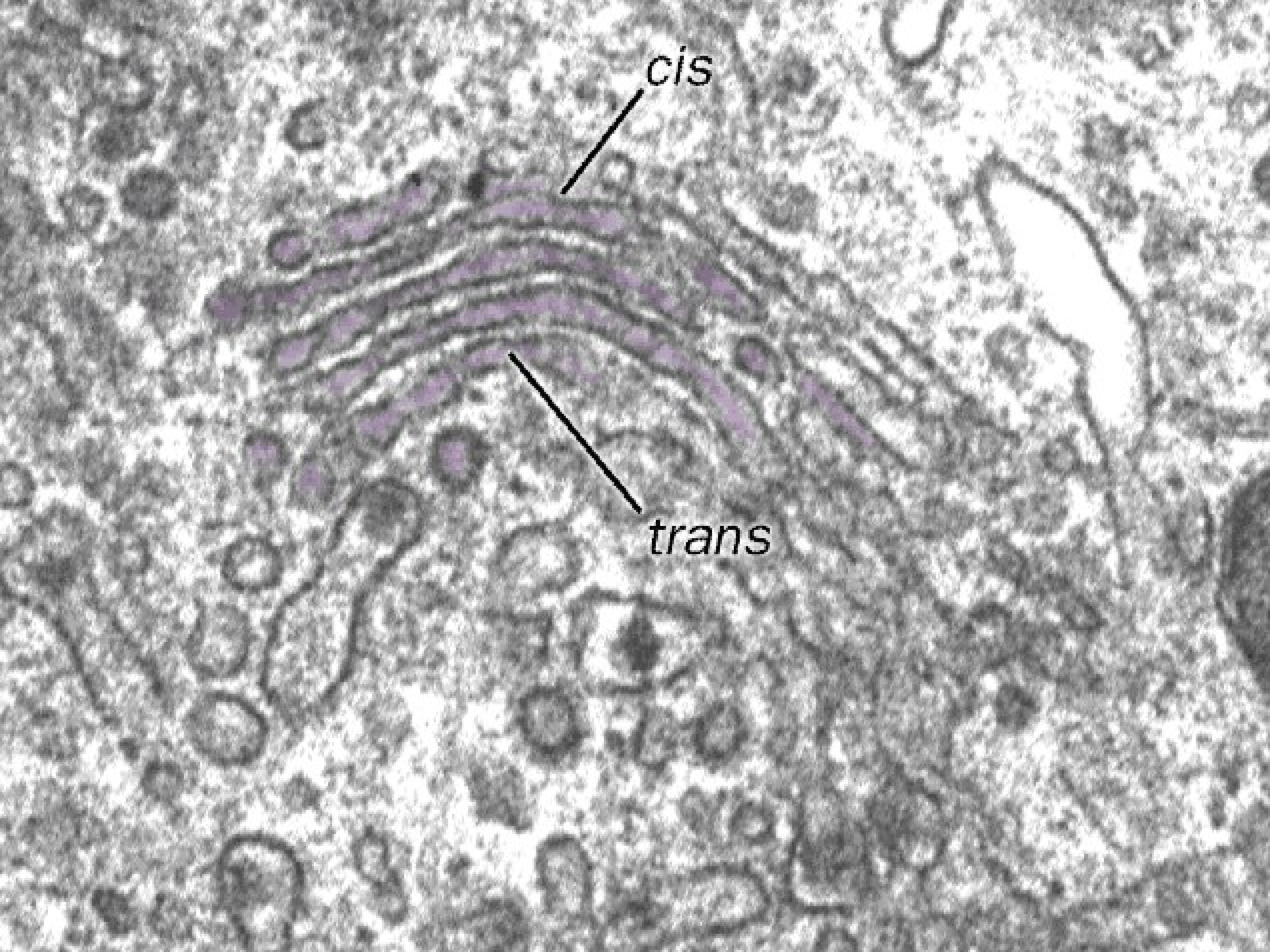




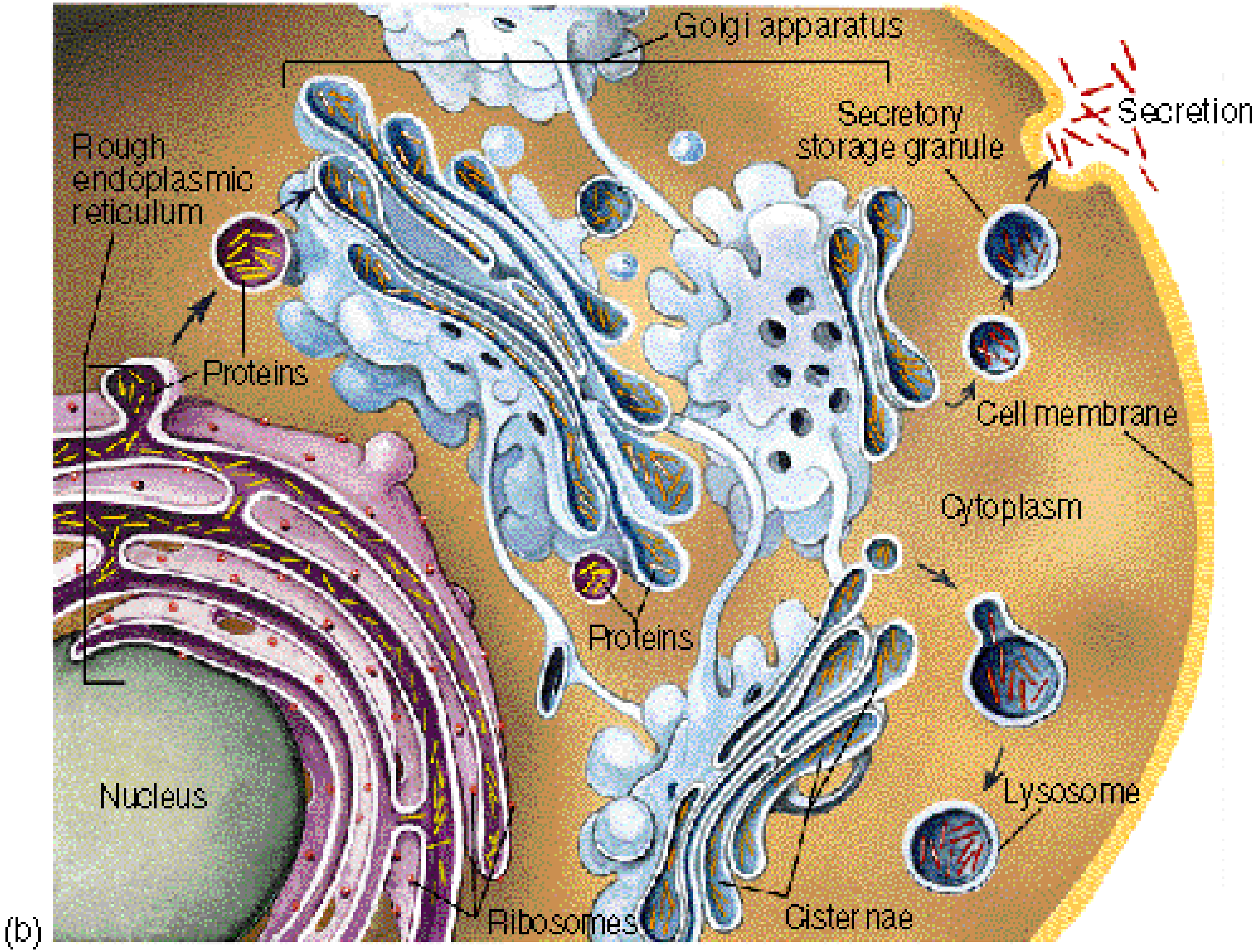
Golgi complex

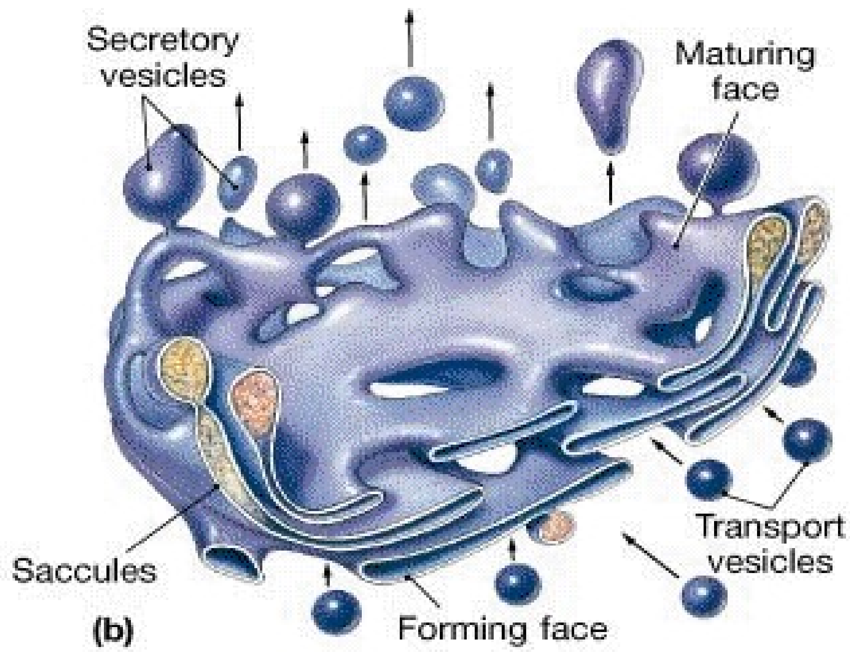


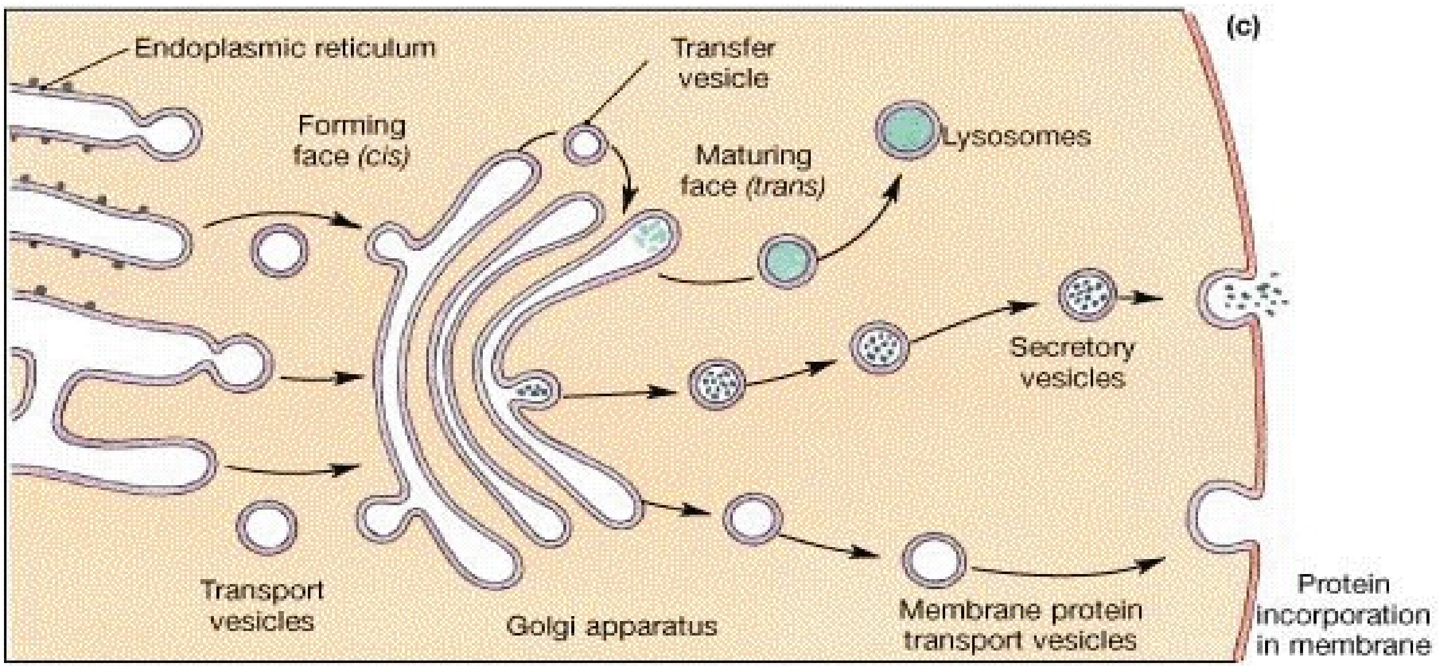

protein synthesis
ER
phosphorylation of lysosomal oligosaccharides
cis
removal of mannose
addition of GlcNAc
medial
addition of Gal
addition of NANA
trans
Golgi
SORTING
TGN
lysosome
secretory vesicle
plasma membrane

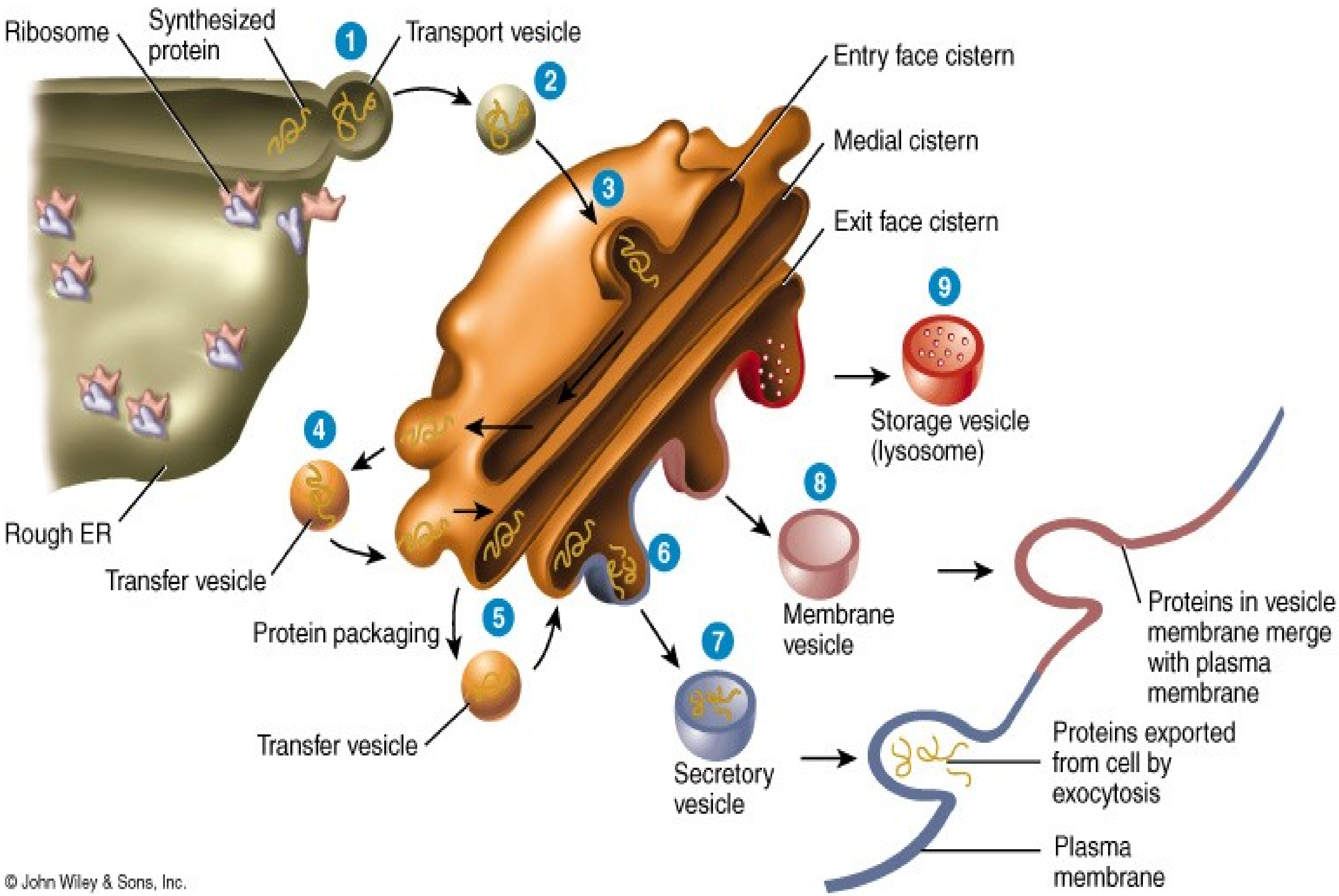

cis
trans

Golgi Apparatus. Figure 3.27b




Secretory vesicles
Maturing face
Saccules
Transport vesicles
Forming face
(b)

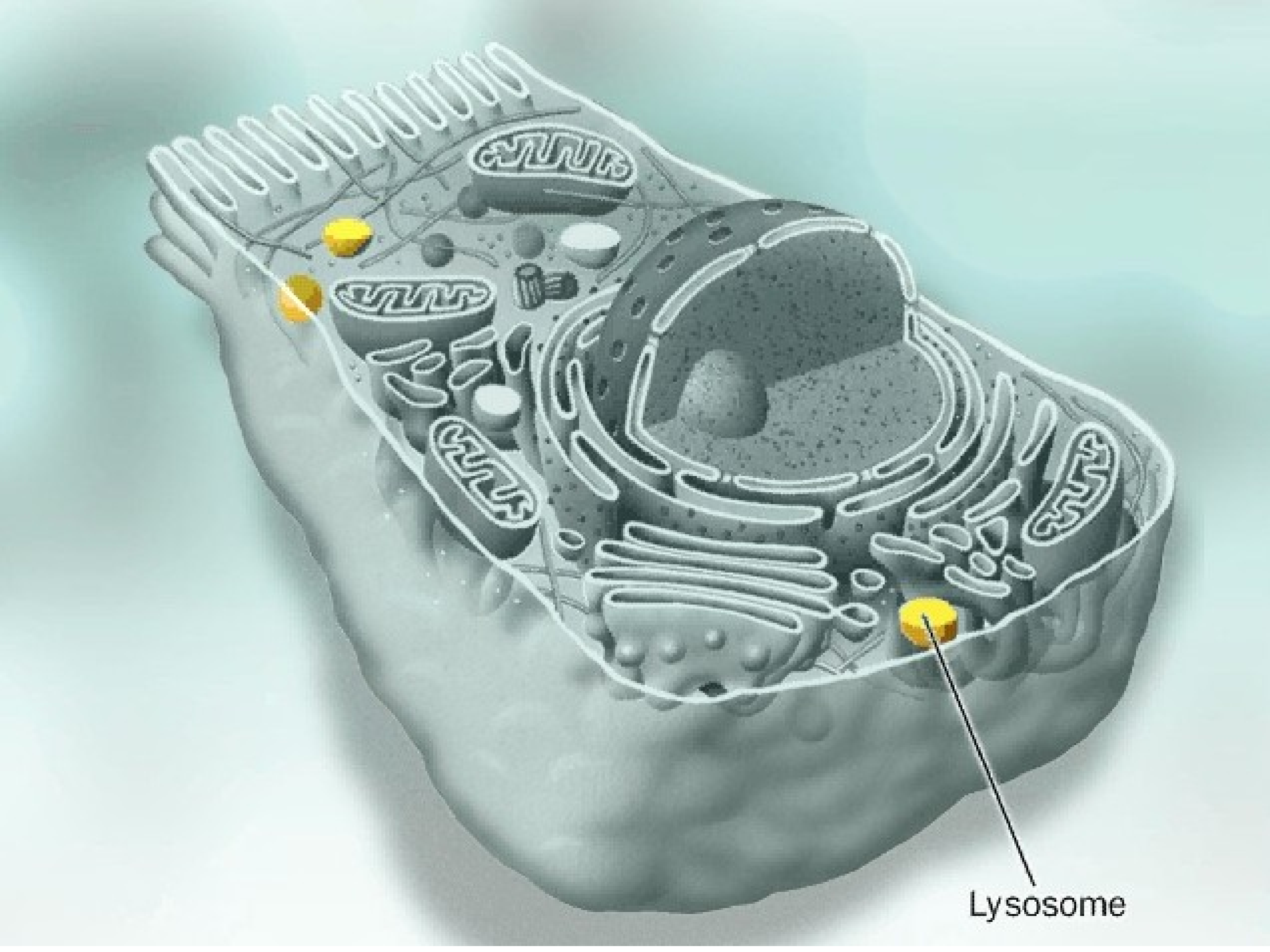

(c)
Endoplasmic reticulum
Transfer vesicle
Forming face (cis)
Maturing face (trans)
Lysosomes
Secretory vesicles
Transport vesicles
Golgi apparatus
Membrane protein transport vesicles
Protein incorporation in membrane



Ribosome
Synthesized protein
1
Transport vesicle
2
Entry face cistern
Medial cistern
3
Exit face cistern
9
Storage vesicle (lysosome)
4
8
Rough ER
Transfer vesicle
6
Membrane vesicle
Proteins in vesicle membrane merge with plasma membrane
Protein packaging
5
7
Transfer vesicle
Secretory vesicle
Proteins exported from cell by exocytosis
Plasma membrane

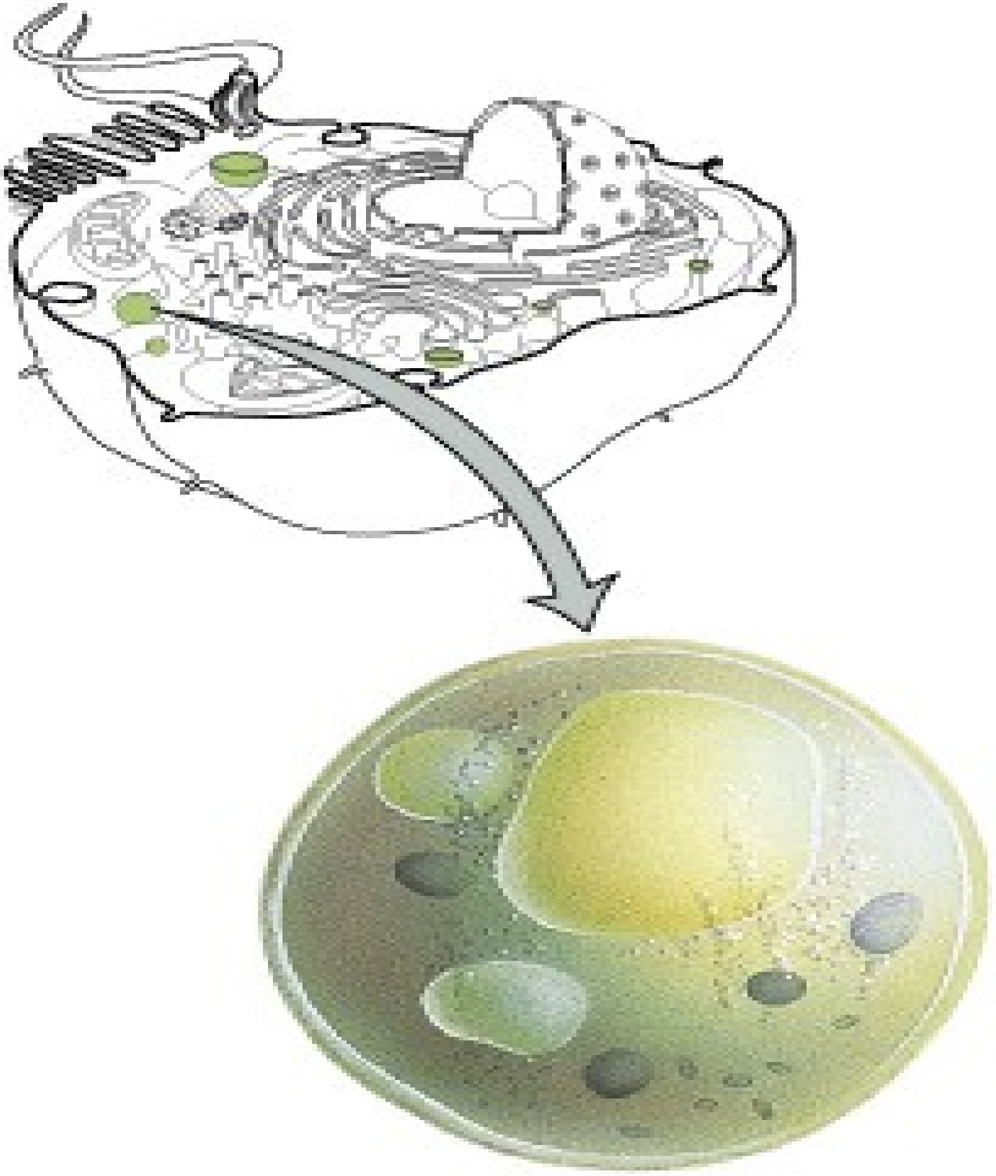
Lysosomes

- *Lysosomes* are membrane-enclosed vesicles that form in the Golgi complex and contain powerful digestive enzymes (Fig. 3.23).
  - Lysosomes function in intracellular digestion, digestion of worn-out organelles (autophagy), digestion of cellular contents (autolysis) during embryological development, and extracellular digestion.

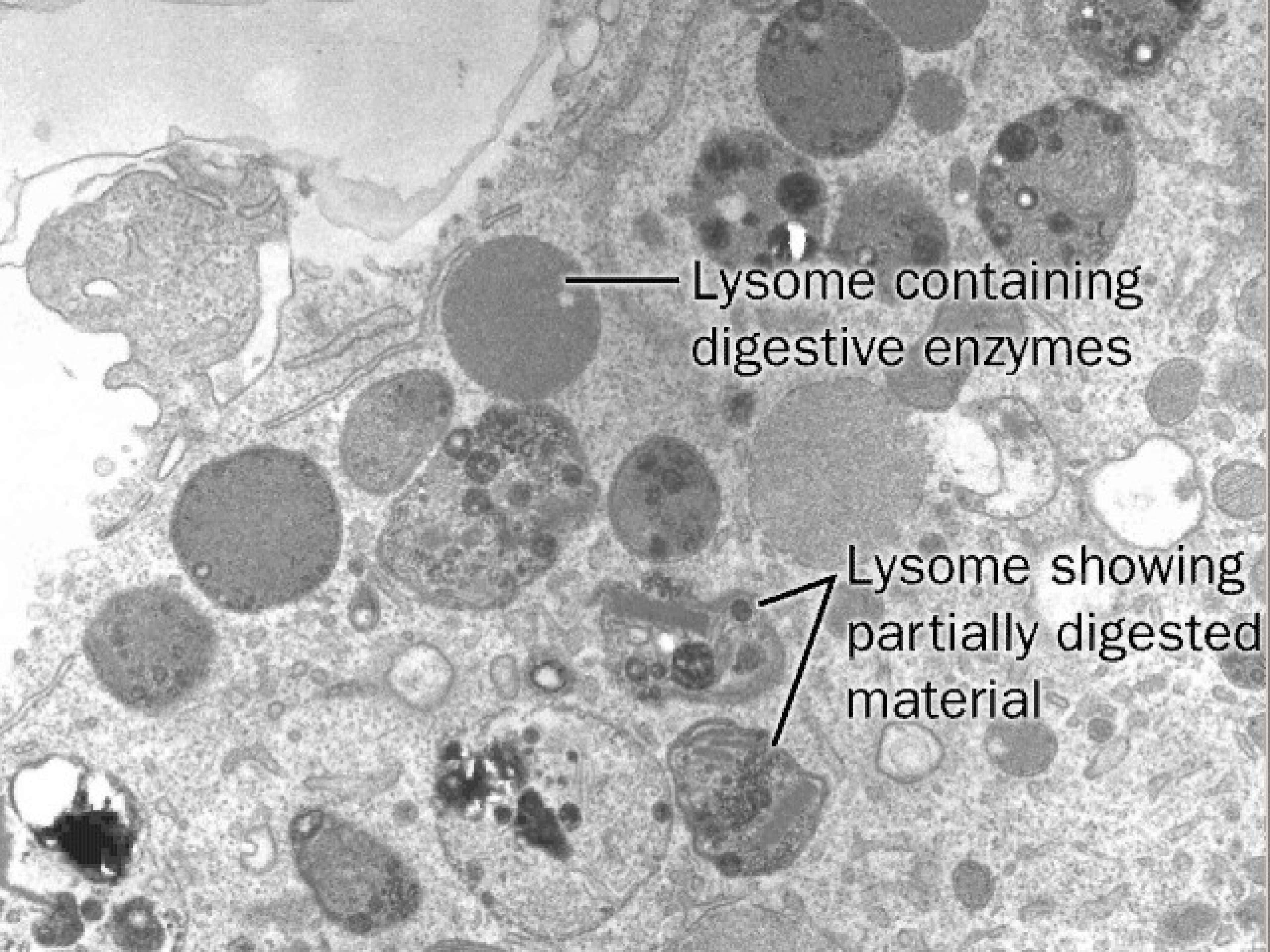

Lysosome

Lysosome

A lysosome is an organelle in animal cells, bounded by a single membrane and containing hydrolytic enzymes. The internal pH of the lysosome is acidic, around 4-5. Lysosomes collaborate with vesicles formed by endocytosis and phagocytosis to digest material imported from the environment.

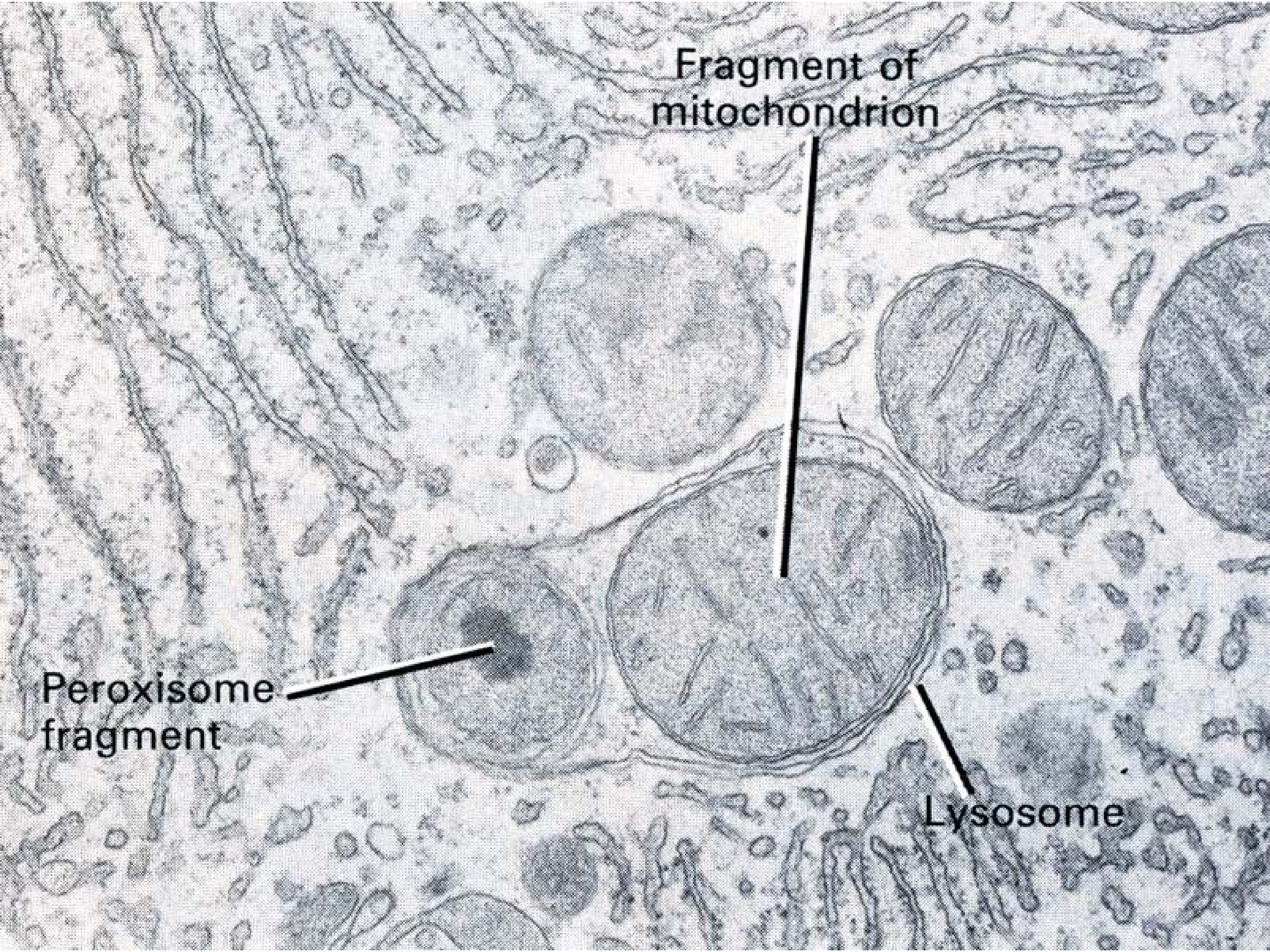


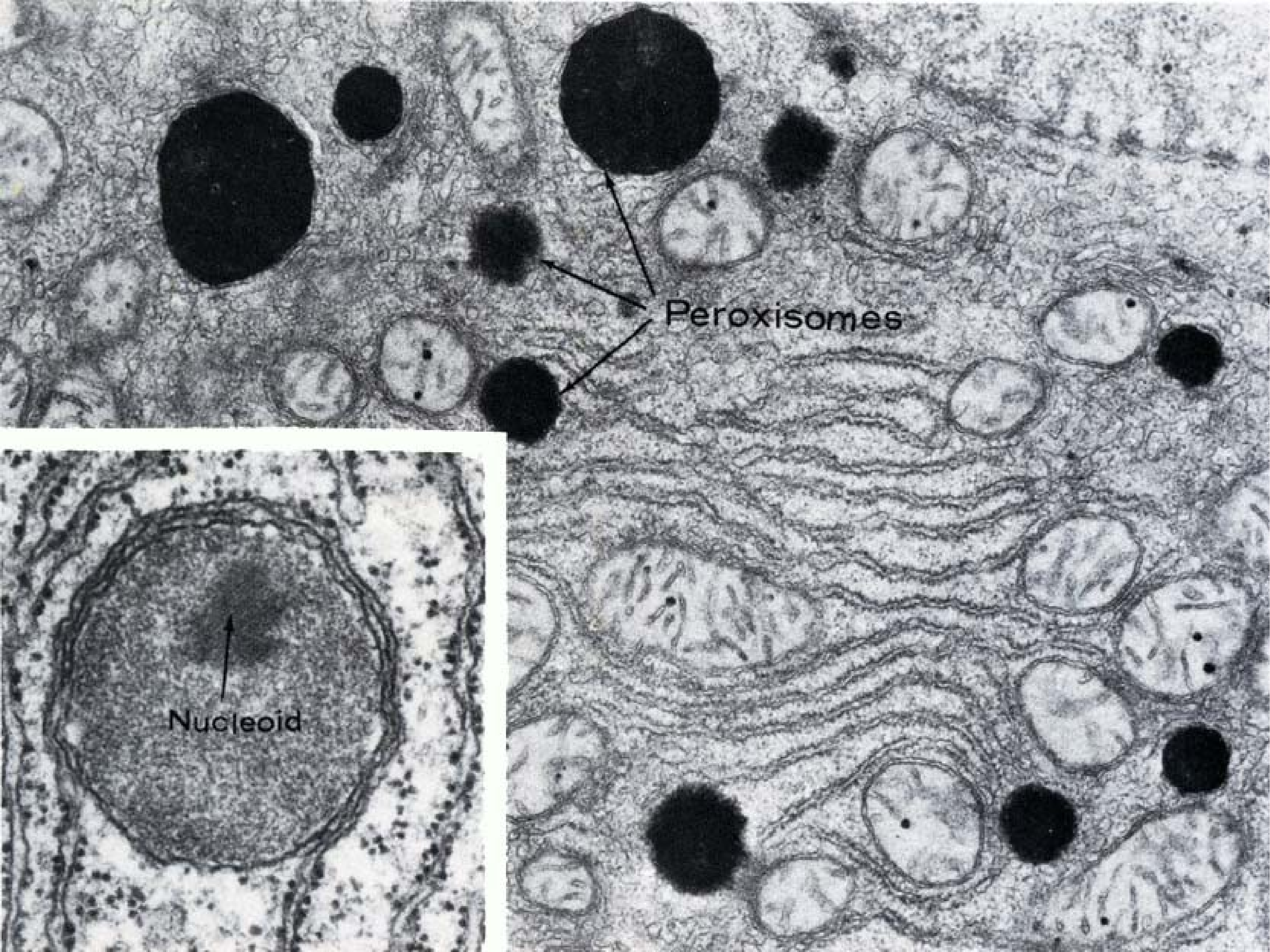
(a) Lysosome


Lysome containing
digestive enzymes
Lysome showing
partially digested
material

Peroxisomes

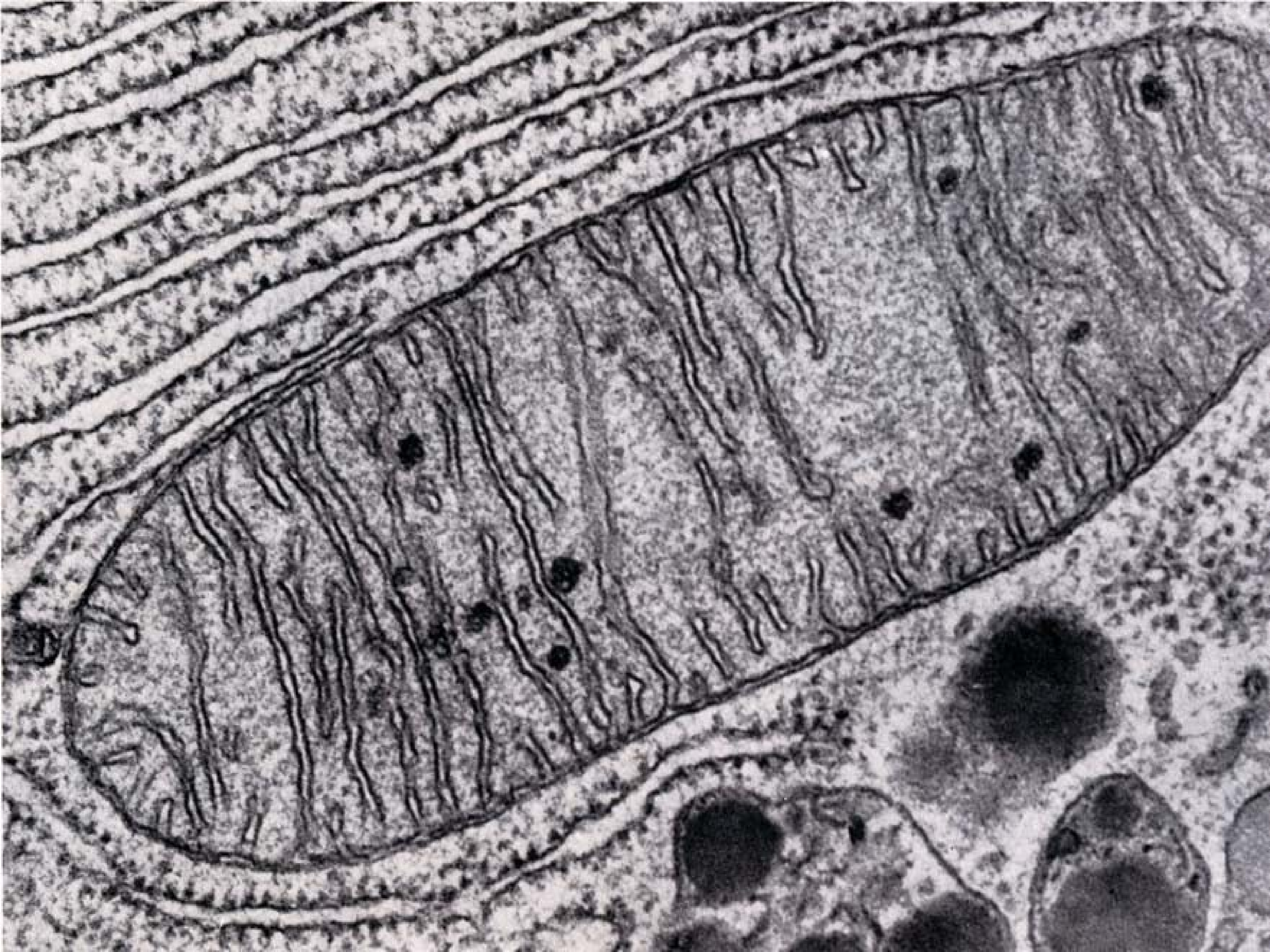
- *Peroxisomes* are similar in structure to lysosomes, but are smaller.
  - They contain enzymes (e.g., catalase) that use molecular oxygen to oxidize various organic substances.

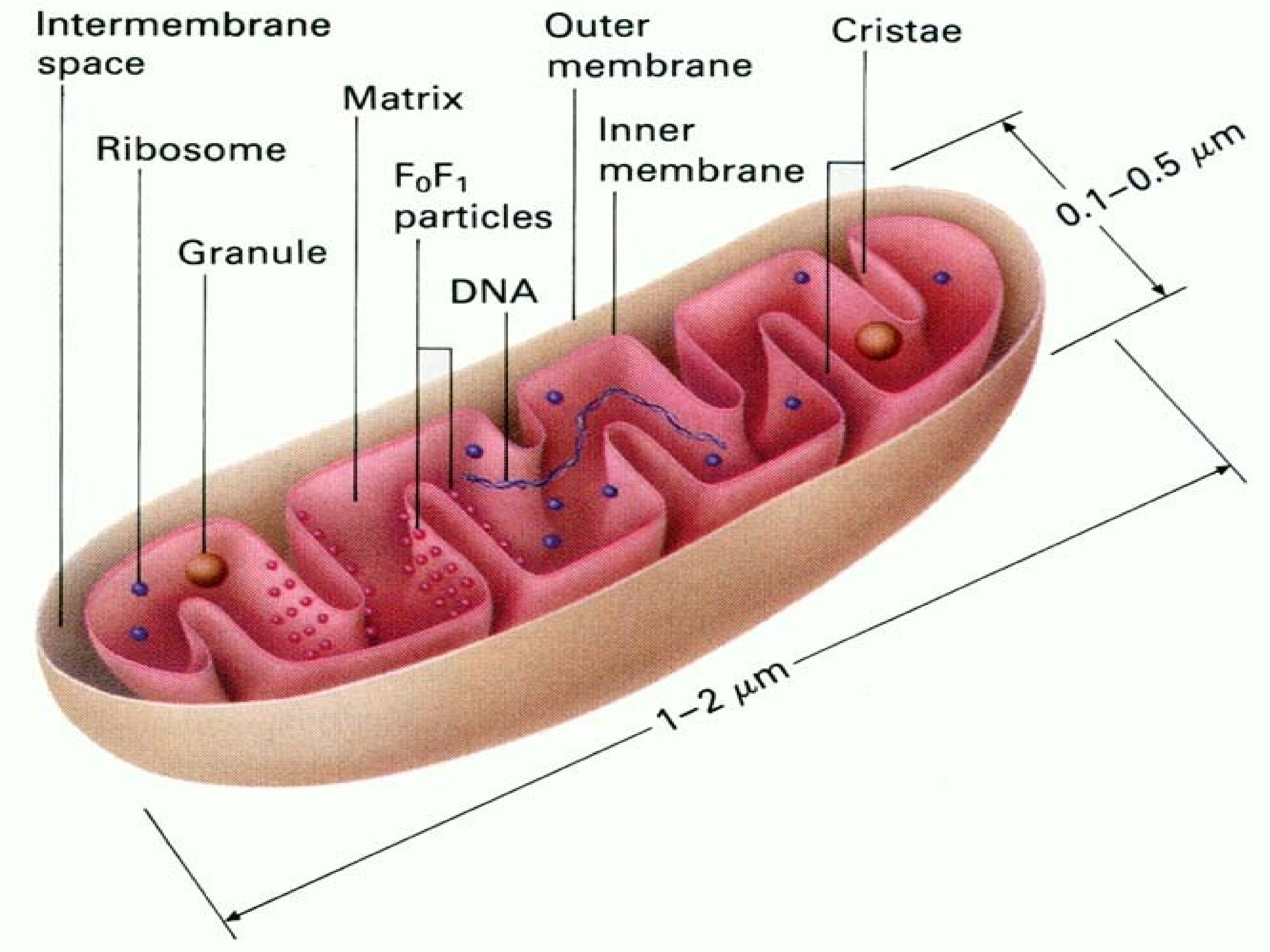

Fragment of mitochondrion
Peroxisome fragment
Lysosome


Peroxisomes
Nucleoid

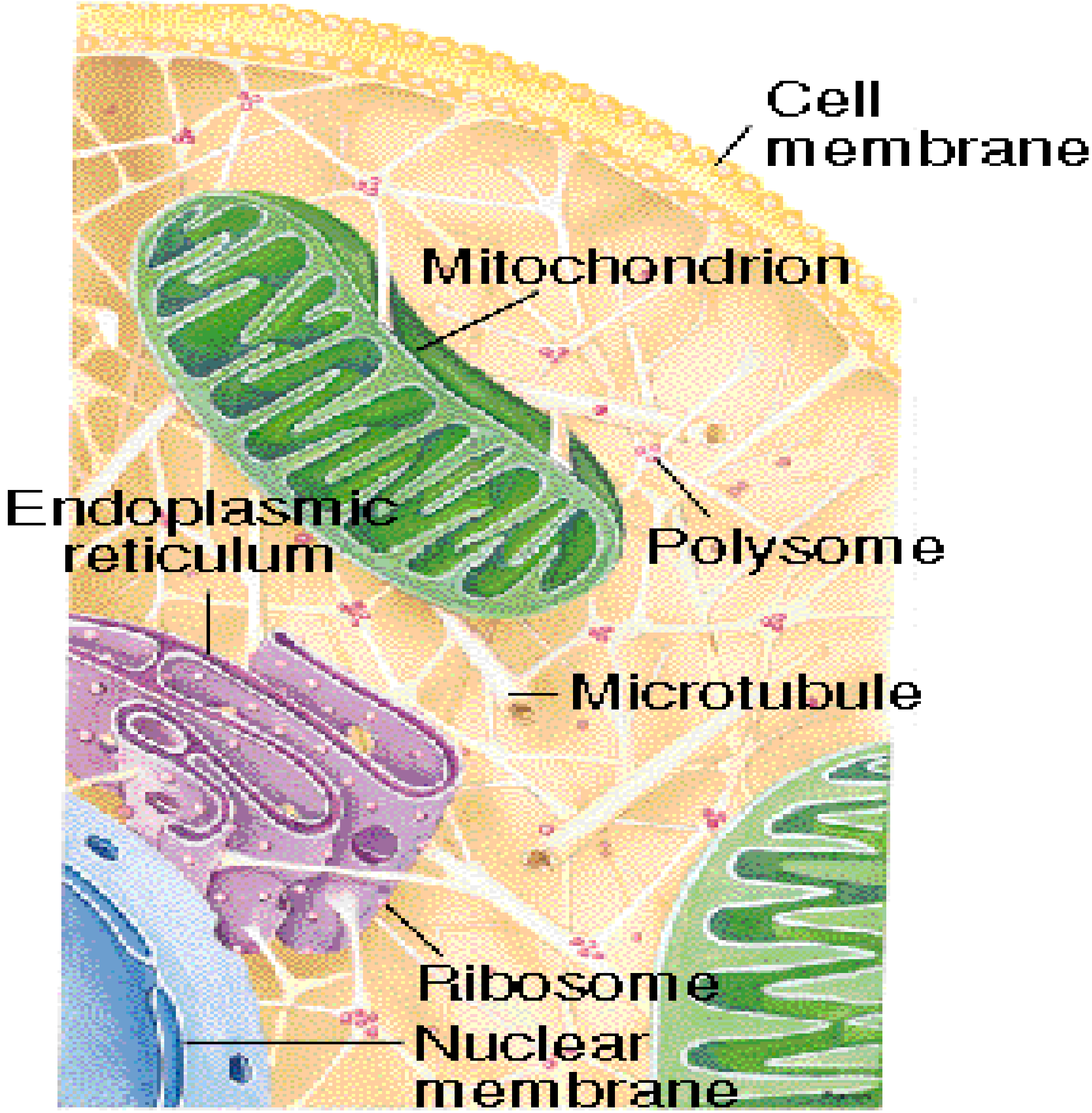
Mitochondria

- The *mitochondrion* is bound by a double membrane. The outer membrane is smooth with the inner membrane arranged in folds called cristae.
  - Mitochondria are the site of ATP production in the cell by the catabolism of nutrient molecules.
  - Mitochondria self-replicate using their own DNA.
  - Mitochondrial DNA (genes) are usually inherited only from the mother.



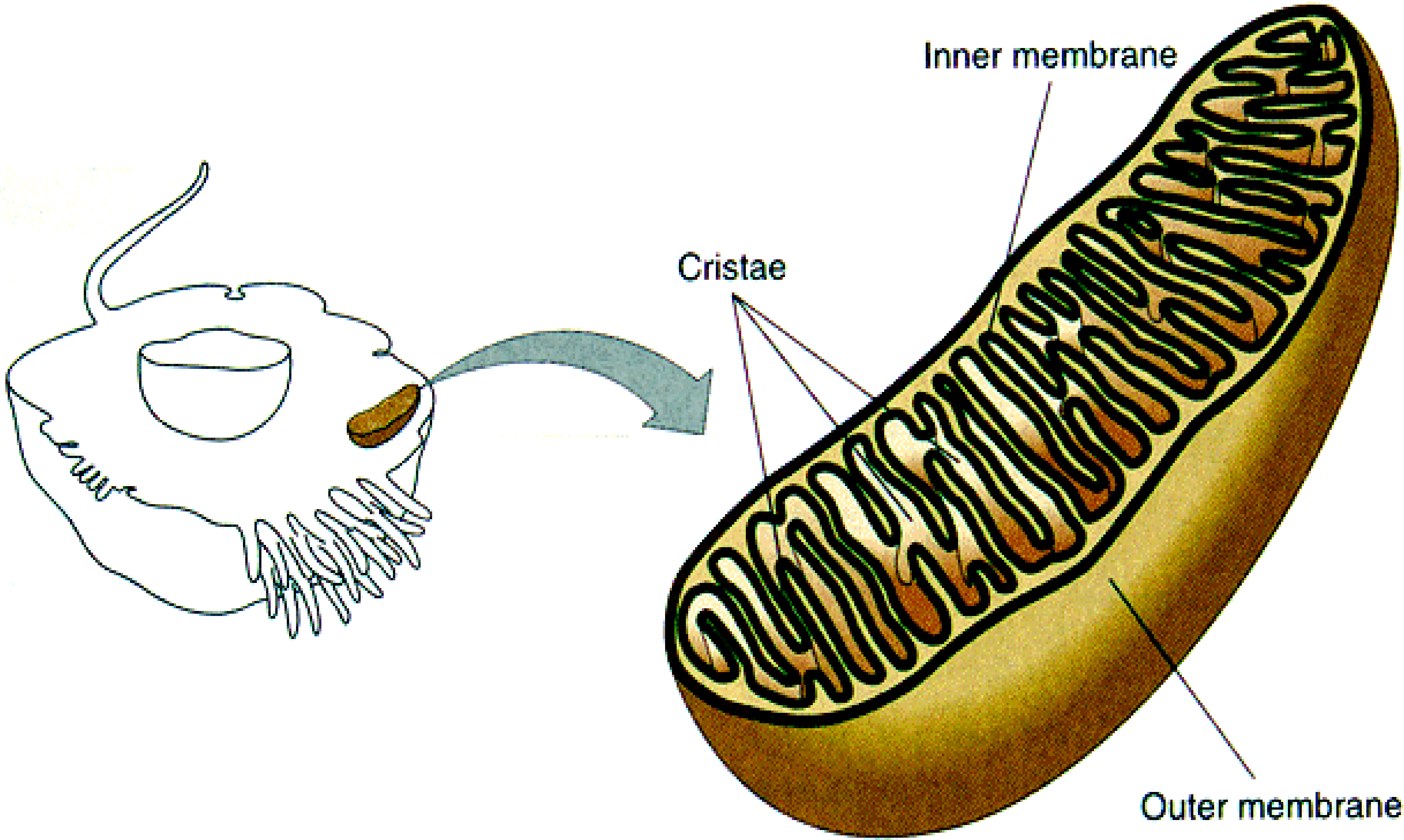


Intermembrane space
Ribosome
Granule
Matrix
F_0F_1 particles
DNA
Outer membrane
Inner membrane
Cristae
0.1–0.5 μm
1–2 μm

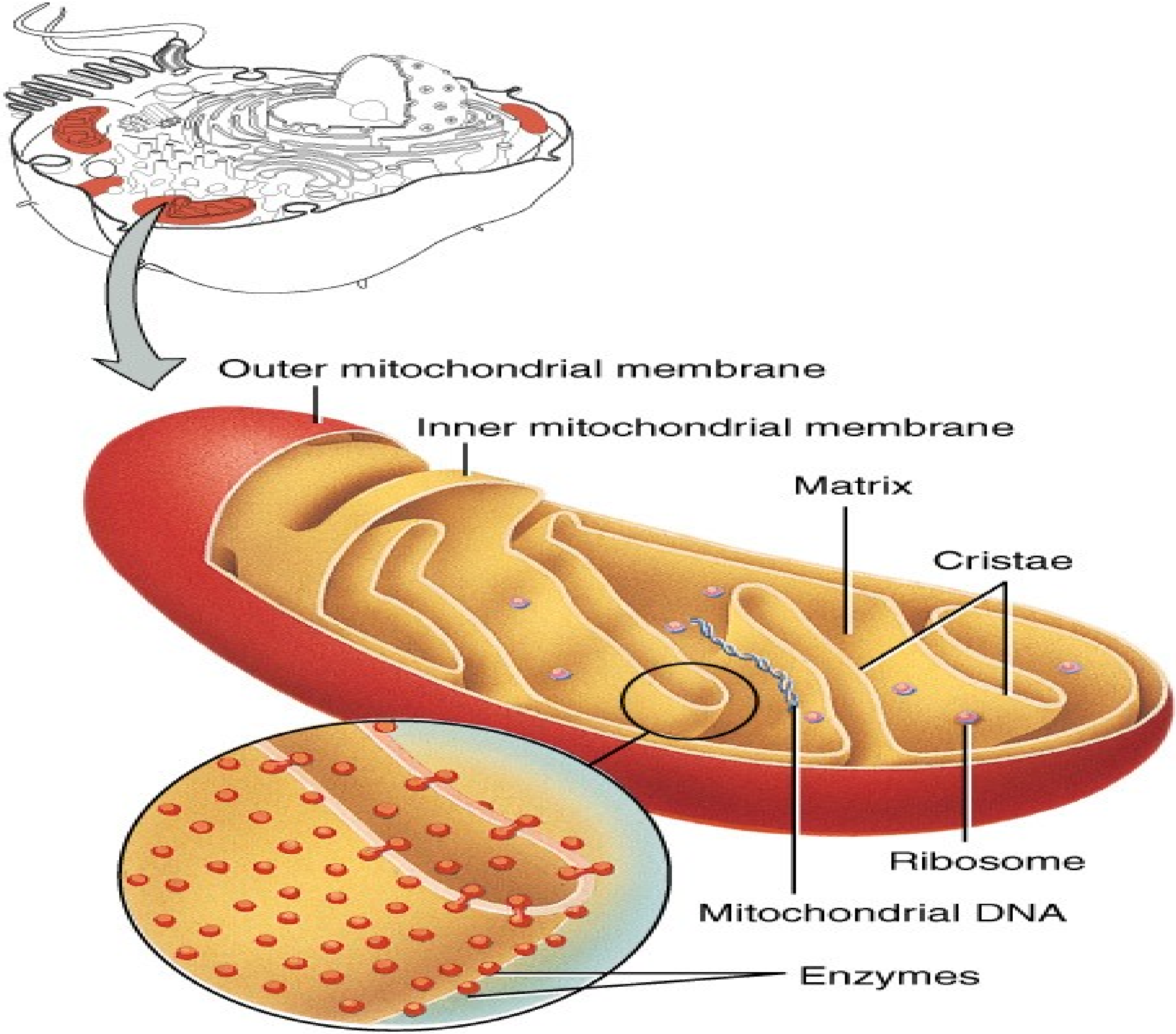


Cell membrane
Mitochondrion
Endoplasmic reticulum
Polysome
Microtubule
Ribosome
Nuclear membrane

Saclike Organelle.



(b)



(a) Mitochrondrial interior

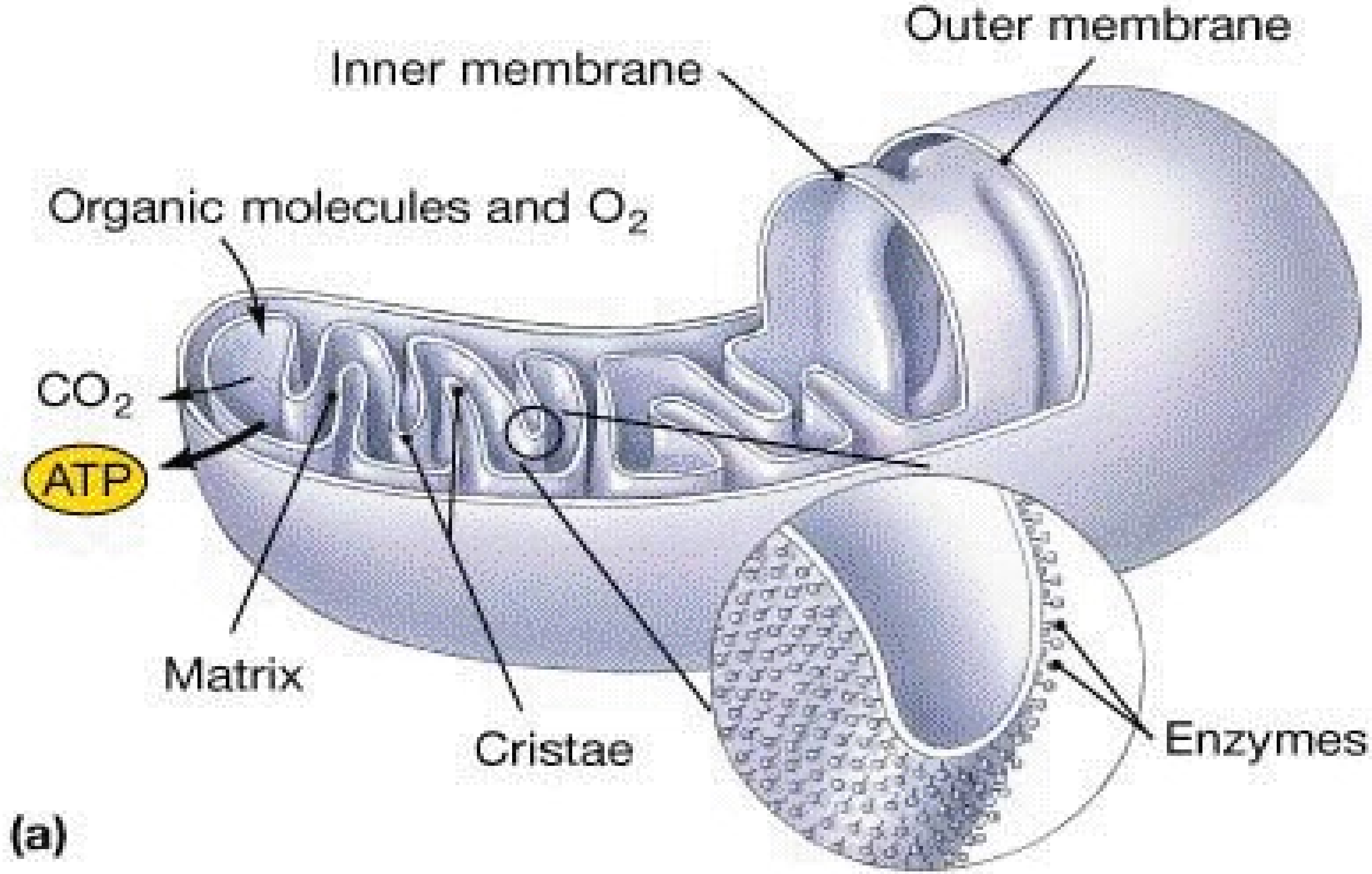
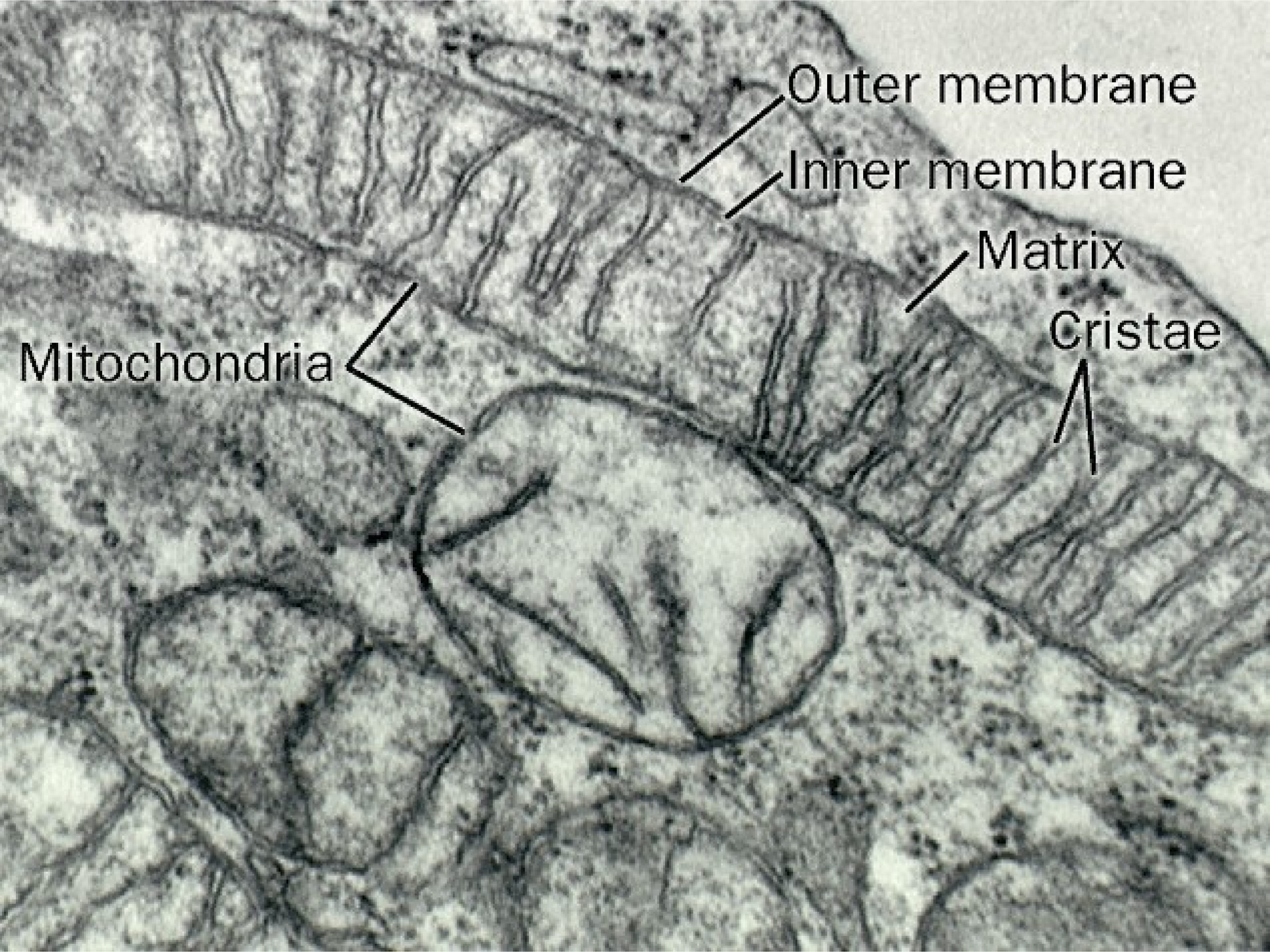


FIGURE 3-16 **Mitochondria. (a)** A typical mitochondrion.



Outer membrane
Inner membrane
Matrix
Cristae
Mitochondria

Figure 6
ATP-synthase complex in the inner mitochondrial membrane.

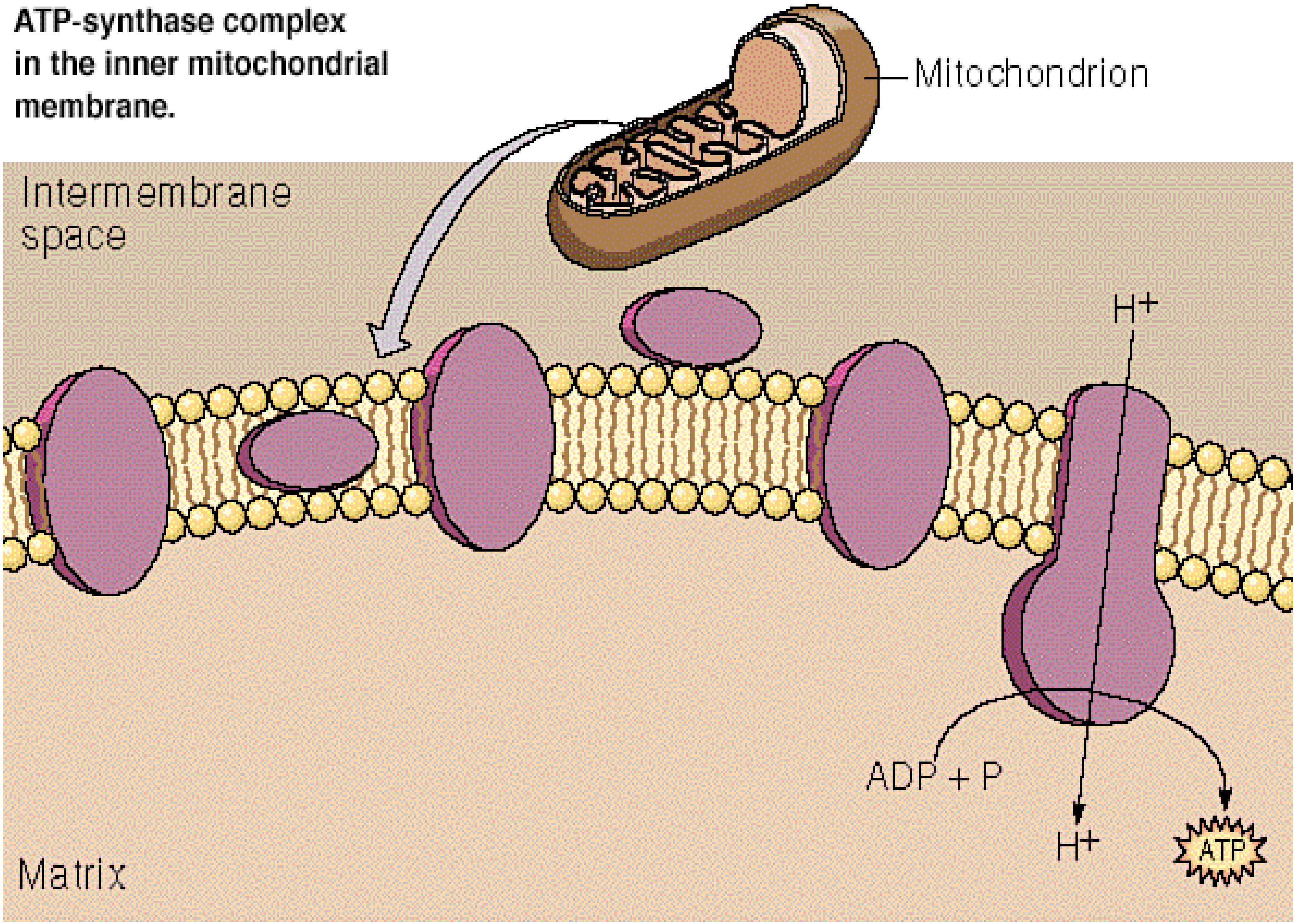


Figure 1
An overview of oxidative respiration.

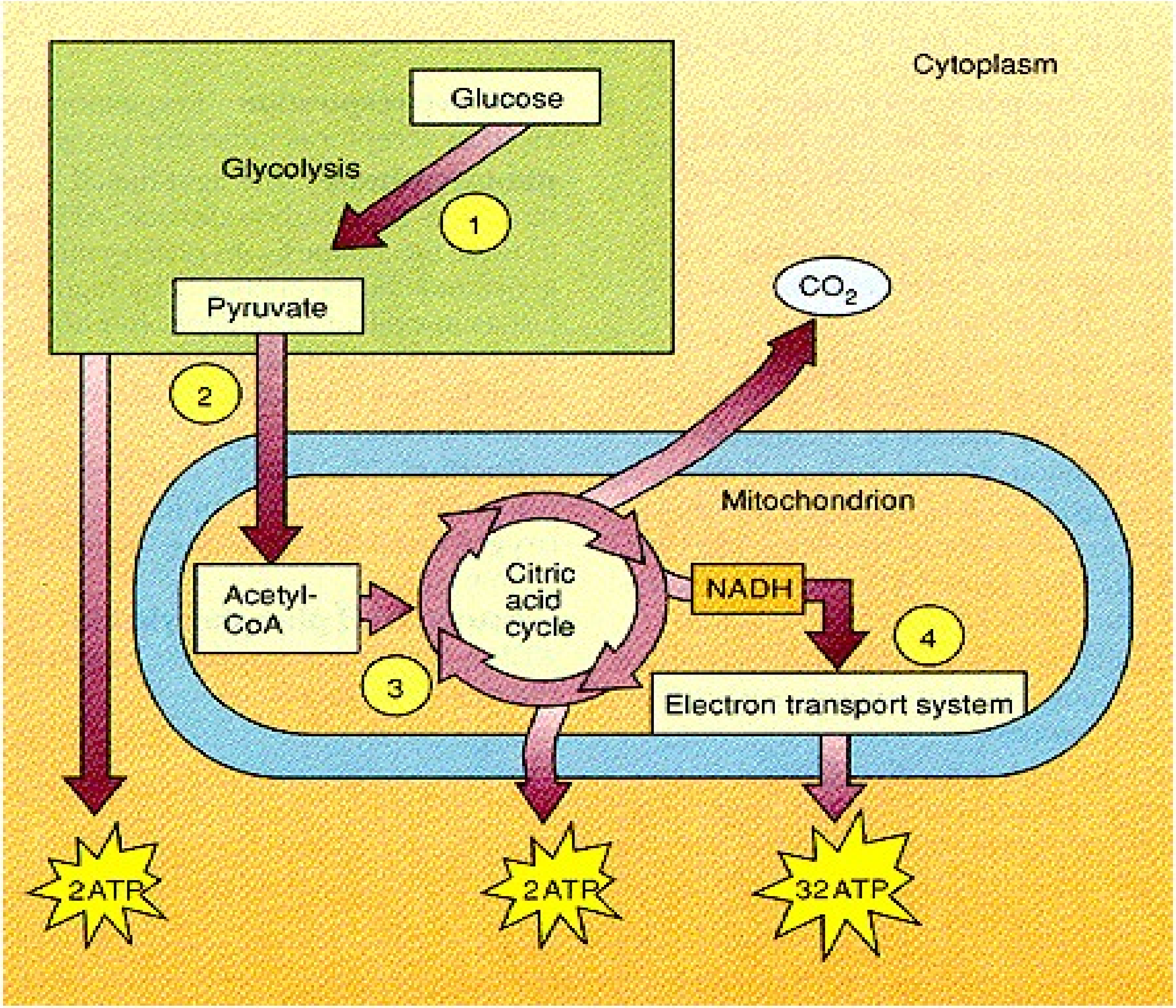


Figure 2
Active transport uses energy released by the hydrolysis of ATP by ATPases in the membrane.

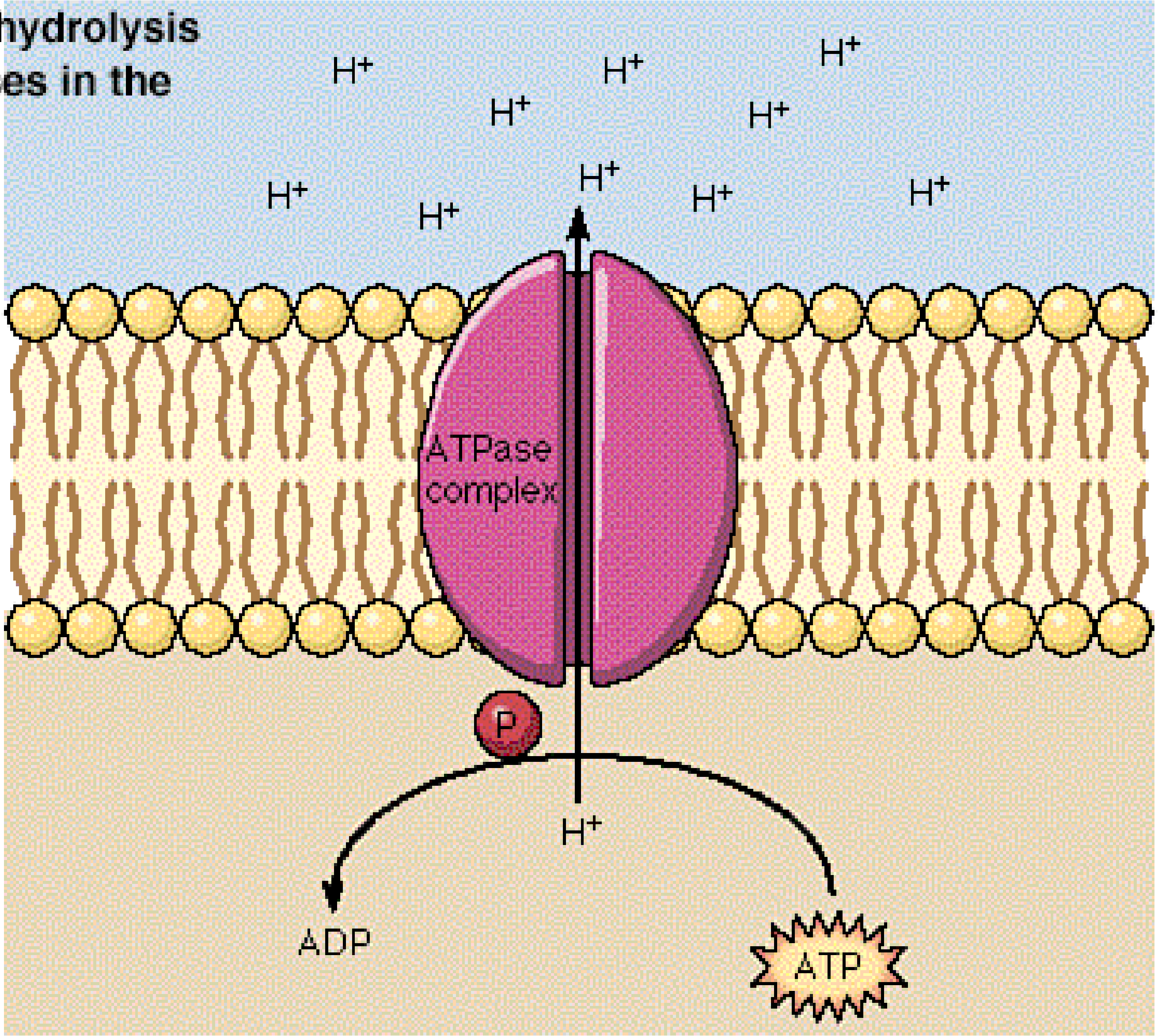


Figure 4
Membranes of chloroplasts and mitochondria use energy stored in a proton gradient to make ATP from ADP and phosphate.

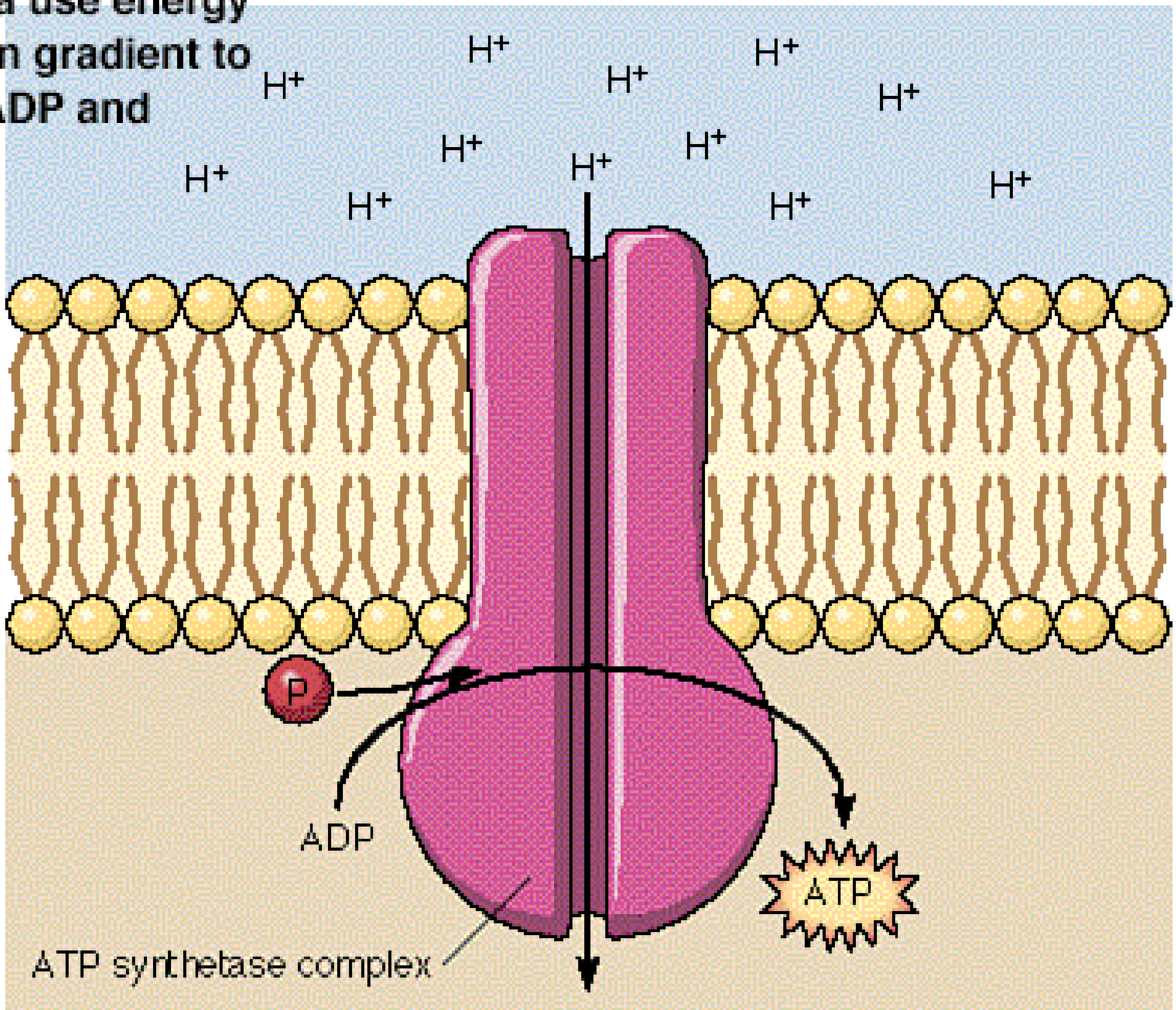


Figure 5
Auxin can induce and amplify proton pumping.

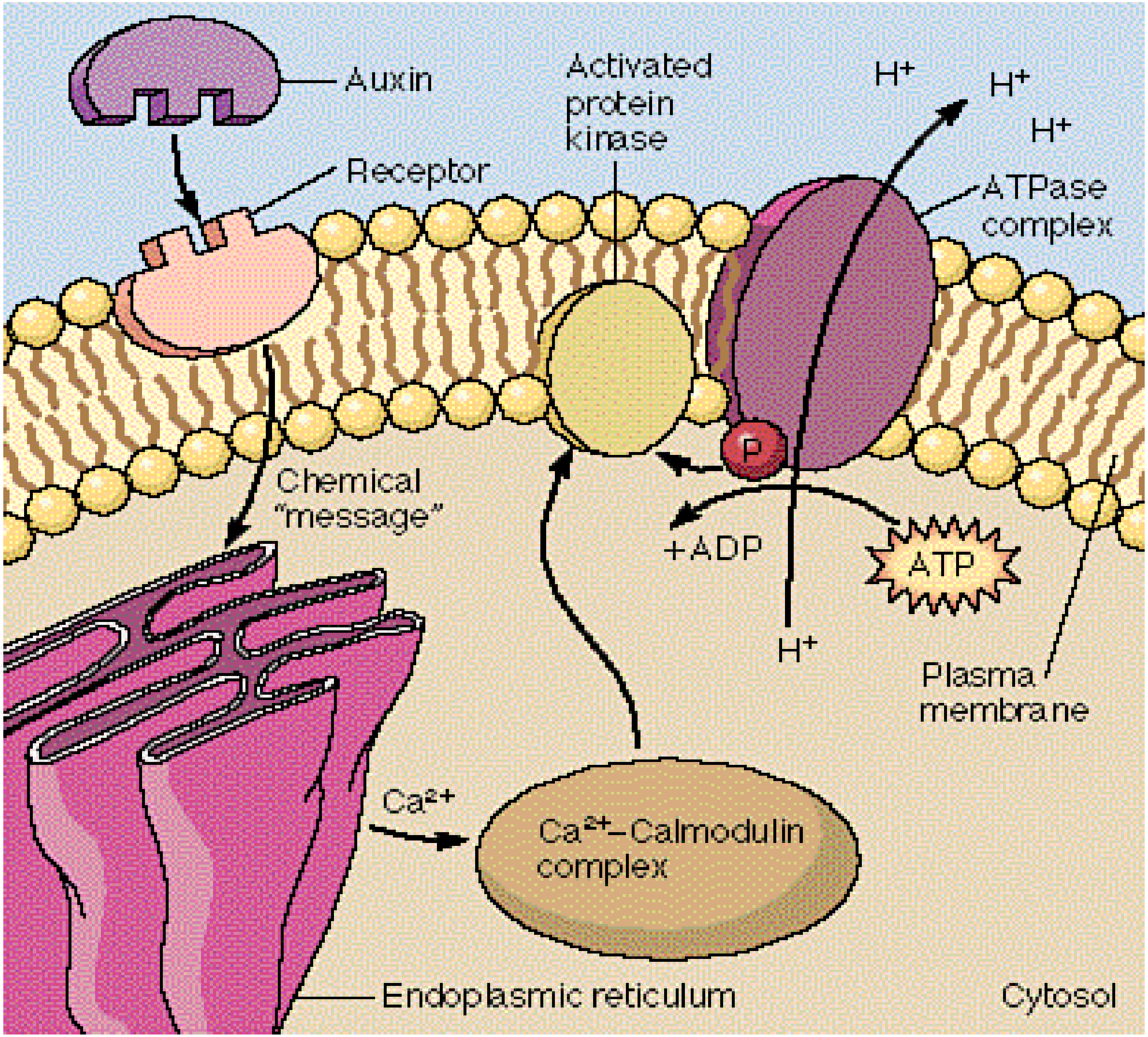
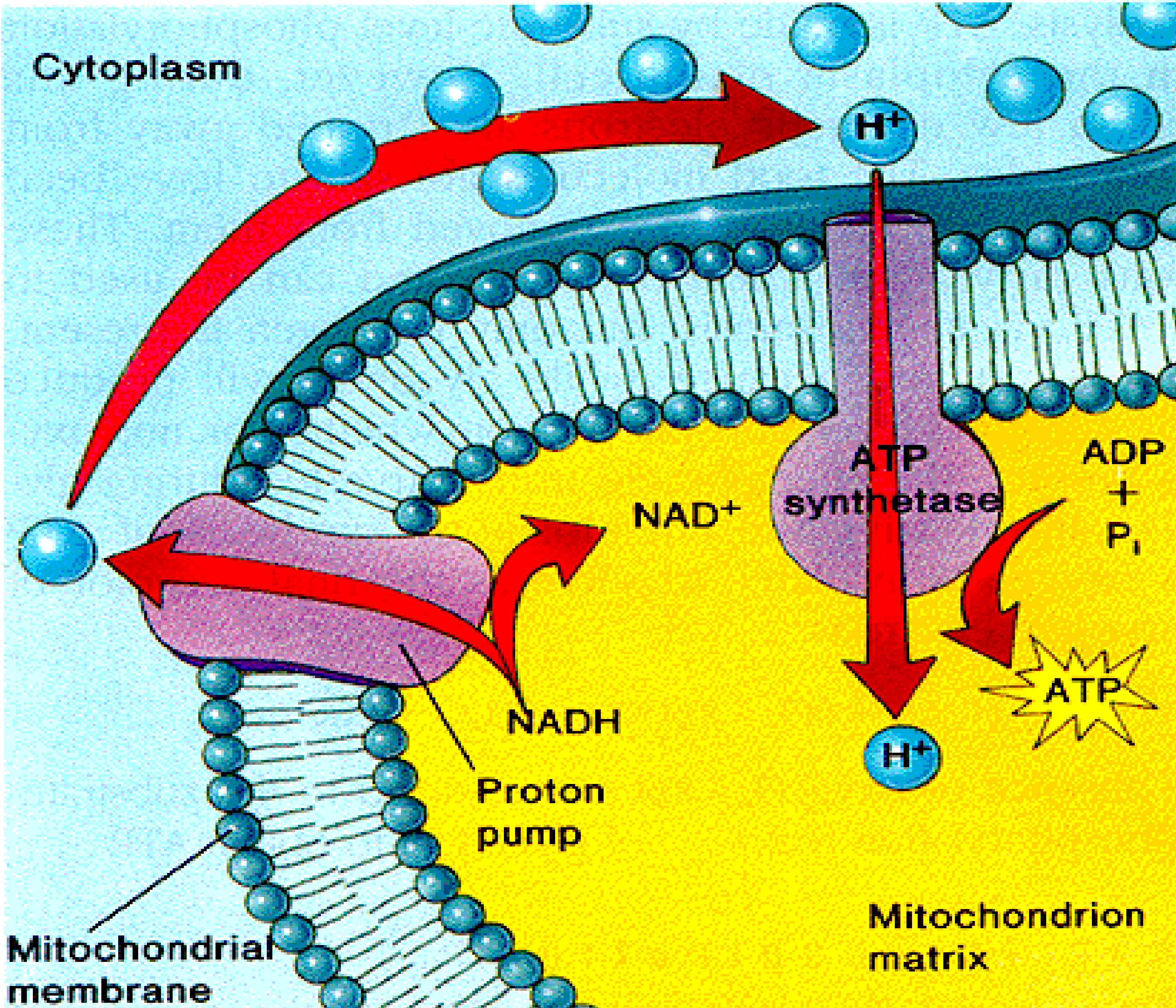


Figure 8
Chemiosmosis.



Centrosomes

- Are dense areas of cytoplasm containing the *centrioles*, which are paired cylinders arranged at right angles to one another, and serve as centers for organizing microtubules in interphase cells and the mitotic spindle during cell division.

Centrosomes/centrioles

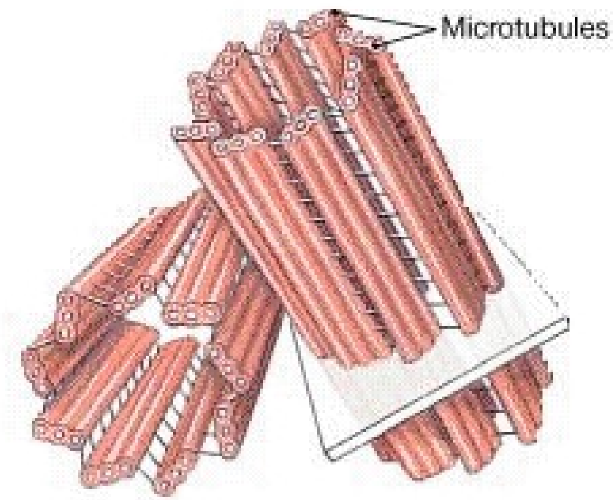
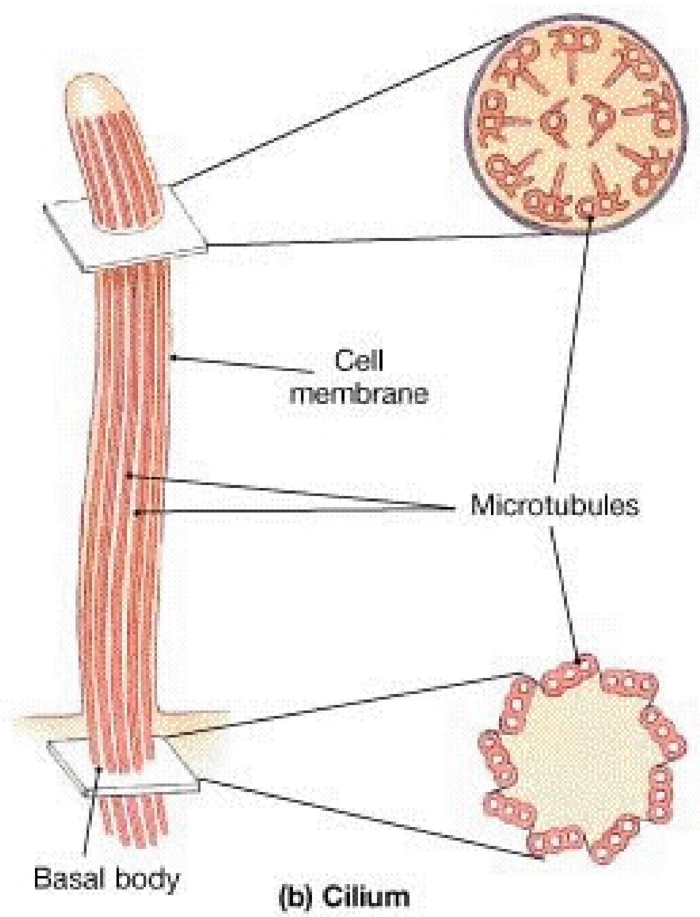
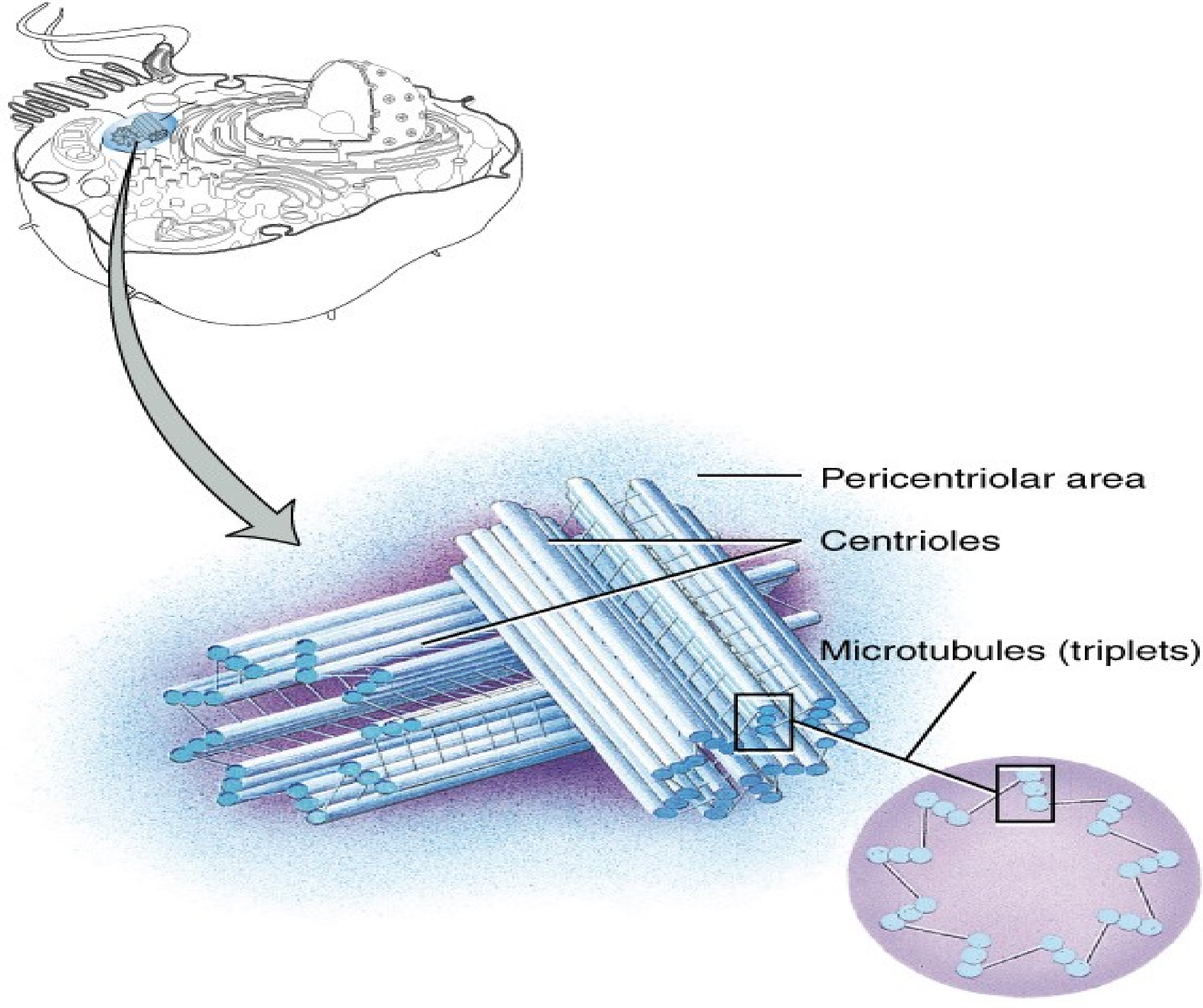


FIGURE 3-14 Centrioles and Cilia. (a) A centriole consists of nine microtubule triplets (known as a 9 + 0 array). The centrosome contains a pair of centrioles oriented at right angles to one another. **(b)** A cilium contains nine pairs of microtubules surrounding a central pair (9 + 2 array). The basal body to which the cilium is anchored has a structure similar to that of a centriole.





(a) Details of a centrosome

(b) 9 + 0 array of centriole

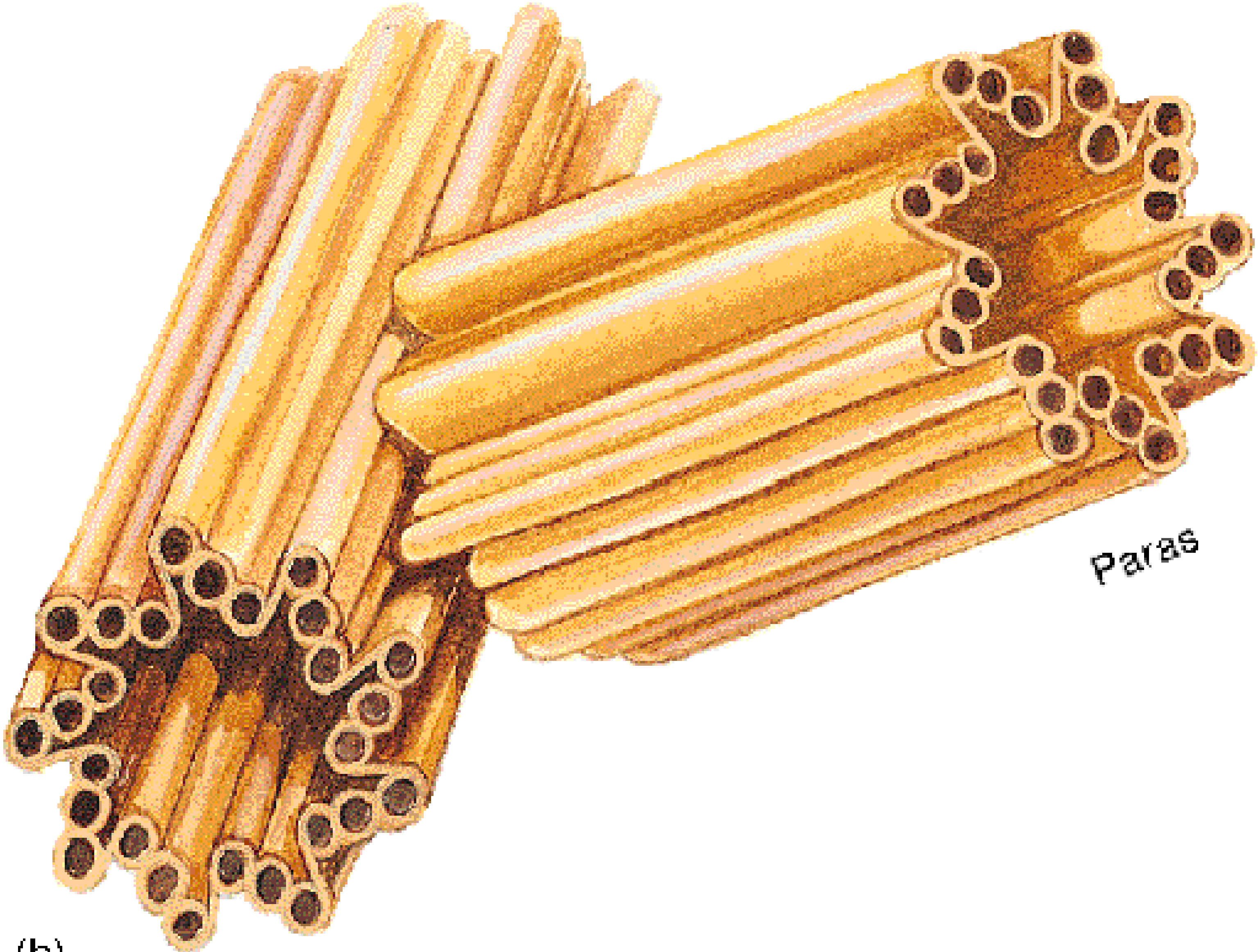
Centrosome

A centrosome, or cell center, lies by the nucleus of animal cells and is the main microtubule organizing center of the cell. Centrosomes in animal cells usually house paired centrioles. Plant cells lack centrosomes.

Centriole

Centrioles are paired organelles composed of microtubules. They are similar in structure to basal bodies. Animal centrosomes typically contain a pair of centrioles lying at right angles to one another. One of the centrioles in a pair is the parent centriole and the other the daughter centriole. Plant cells lack centrioles.

Centrioles. Figure 3.32b



(b)

ORGANELLES

- **Nucleus**
  - Normally one/cell
    - RBC’s have none
    - Muscle cells have two or more
  - Nuclear membrane
  - Nucleoli - site of ribosome production
  - Genes and chromosomes

Nucleus

- The ***nucleus*** is usually the most prominent feature of a cell with most body cells having a single nucleus; some (**red blood cells**) have **none**, whereas others (skeletal muscle fibers) have several.

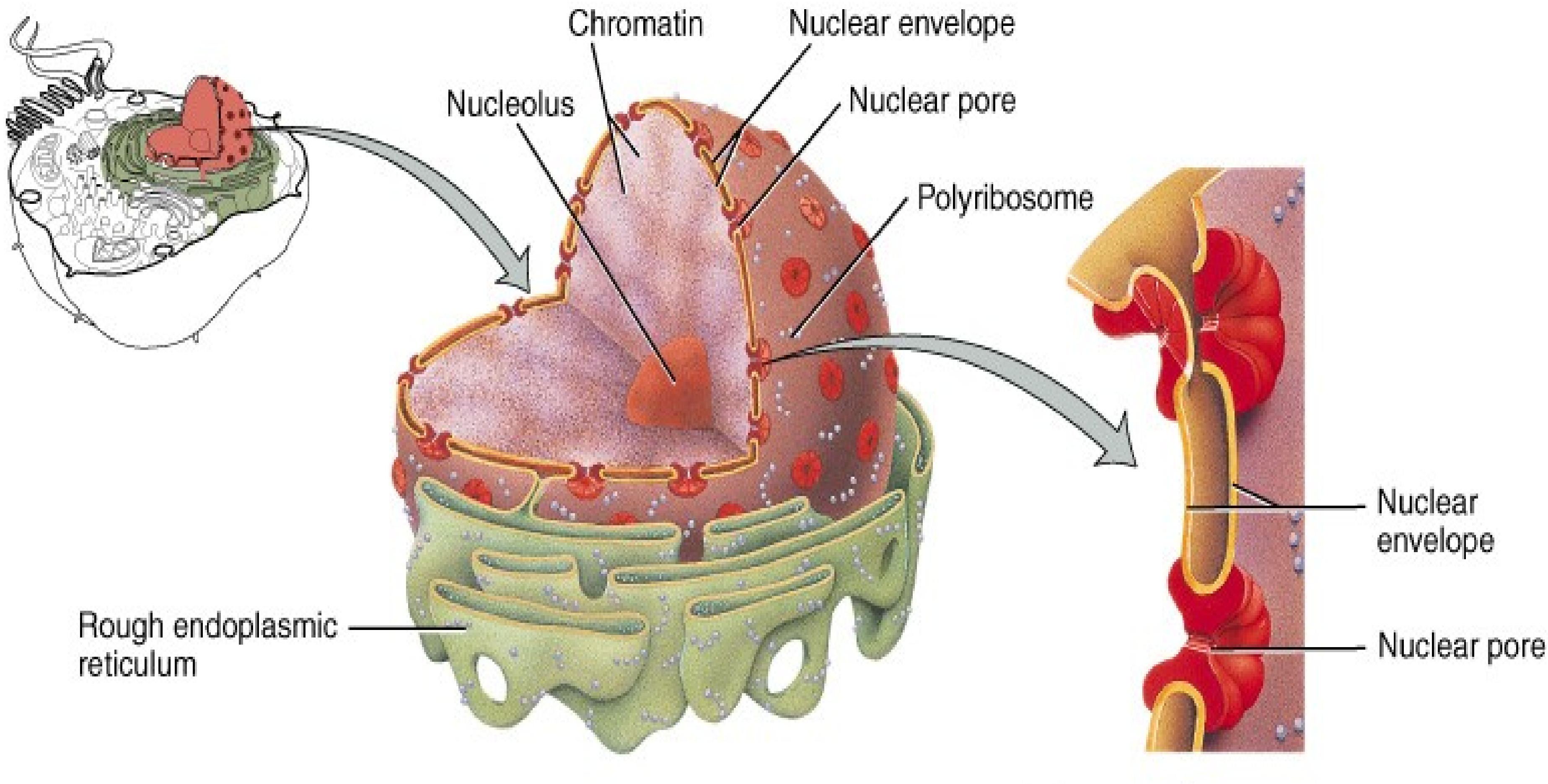
Nucleus

- The parts of the nucleus include the ***nuclear envelope*** which is perforated by channels called **nuclear pores**, **nucleoli**, and **genetic material (DNA)**
- Within the nucleus are the cell's hereditary units, called ***genes***, which are arranged in single file along chromosomes.
- Each chromosome is a long molecule of DNA that is coiled together with several proteins (Fig. 3.26).

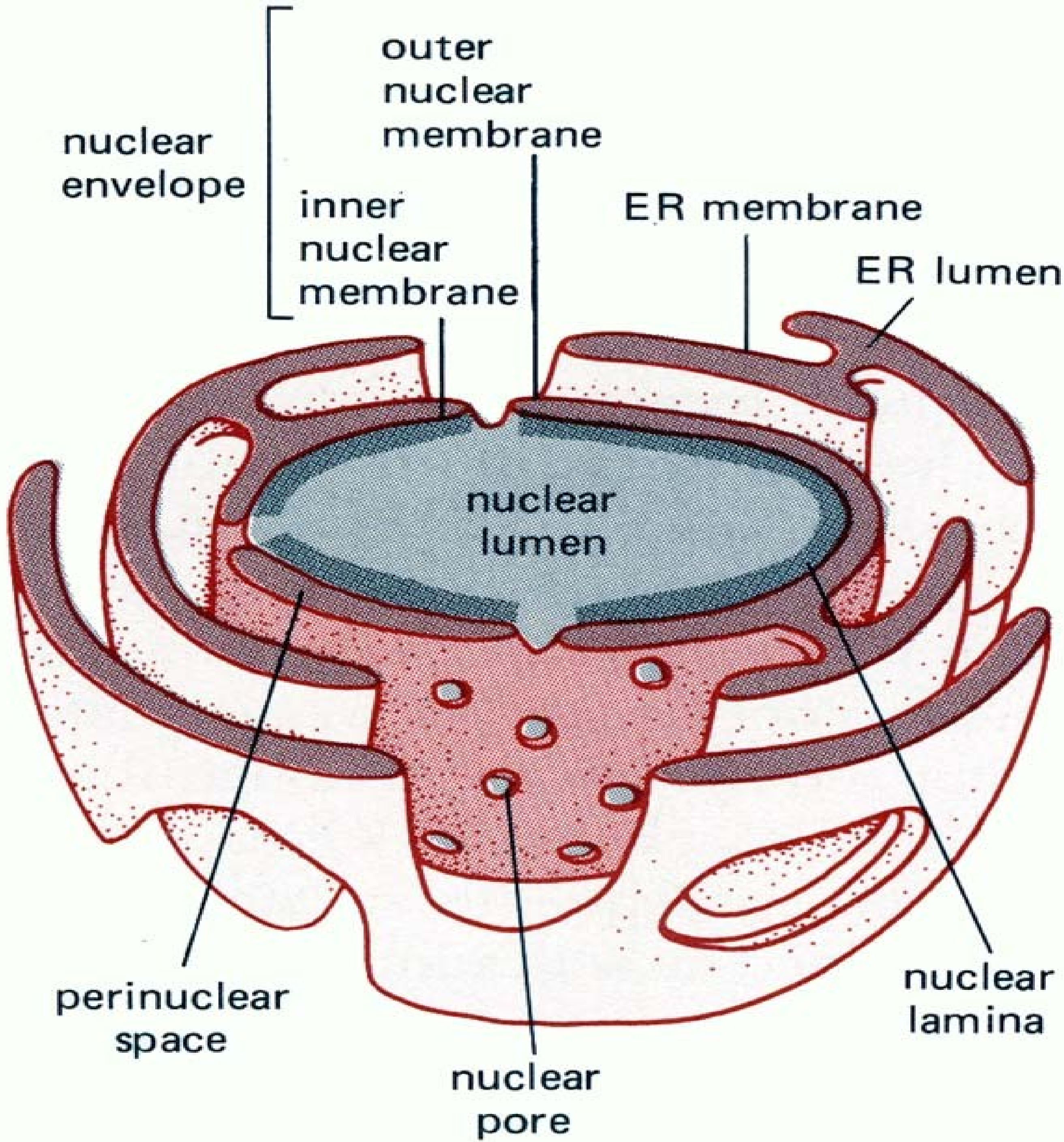
Nucleus

- Human somatic cells have 46 chromosomes arranged in **23 pairs**.
- The various levels of DNA packing are represented by **nucleosomes**, **chromatin** fibers, loops, **chromatids**, and **chromosomes**.

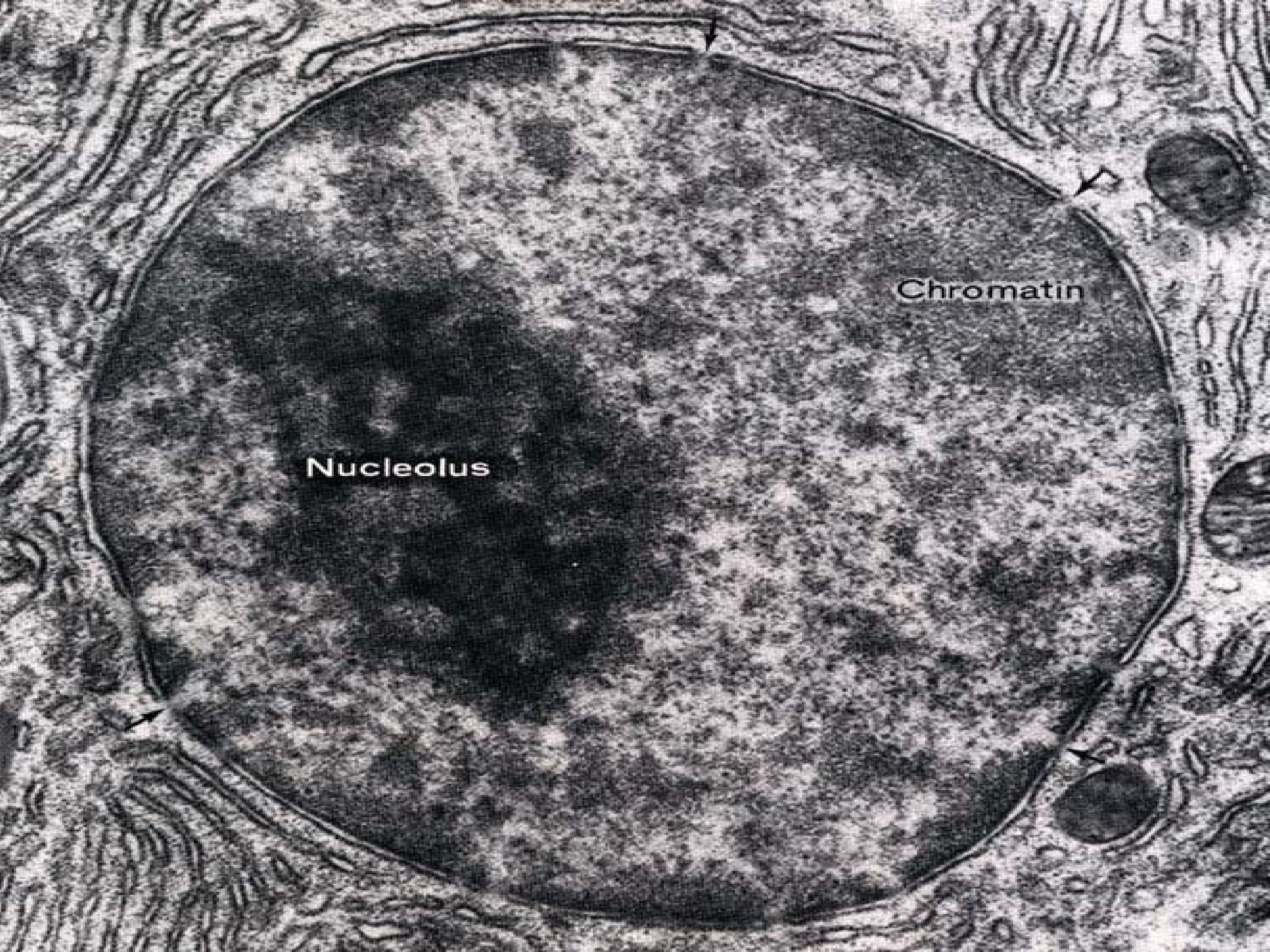
Nucleus

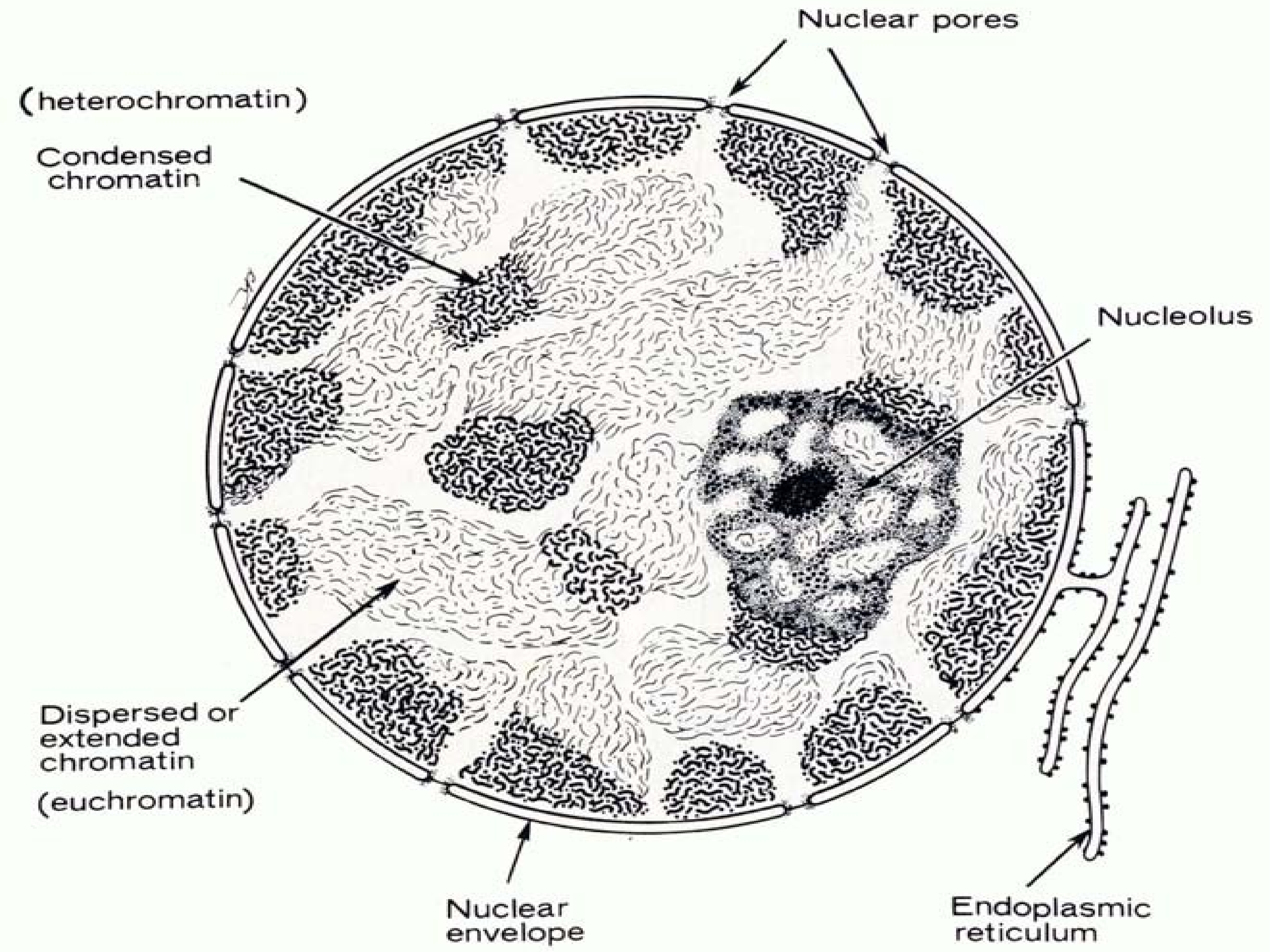


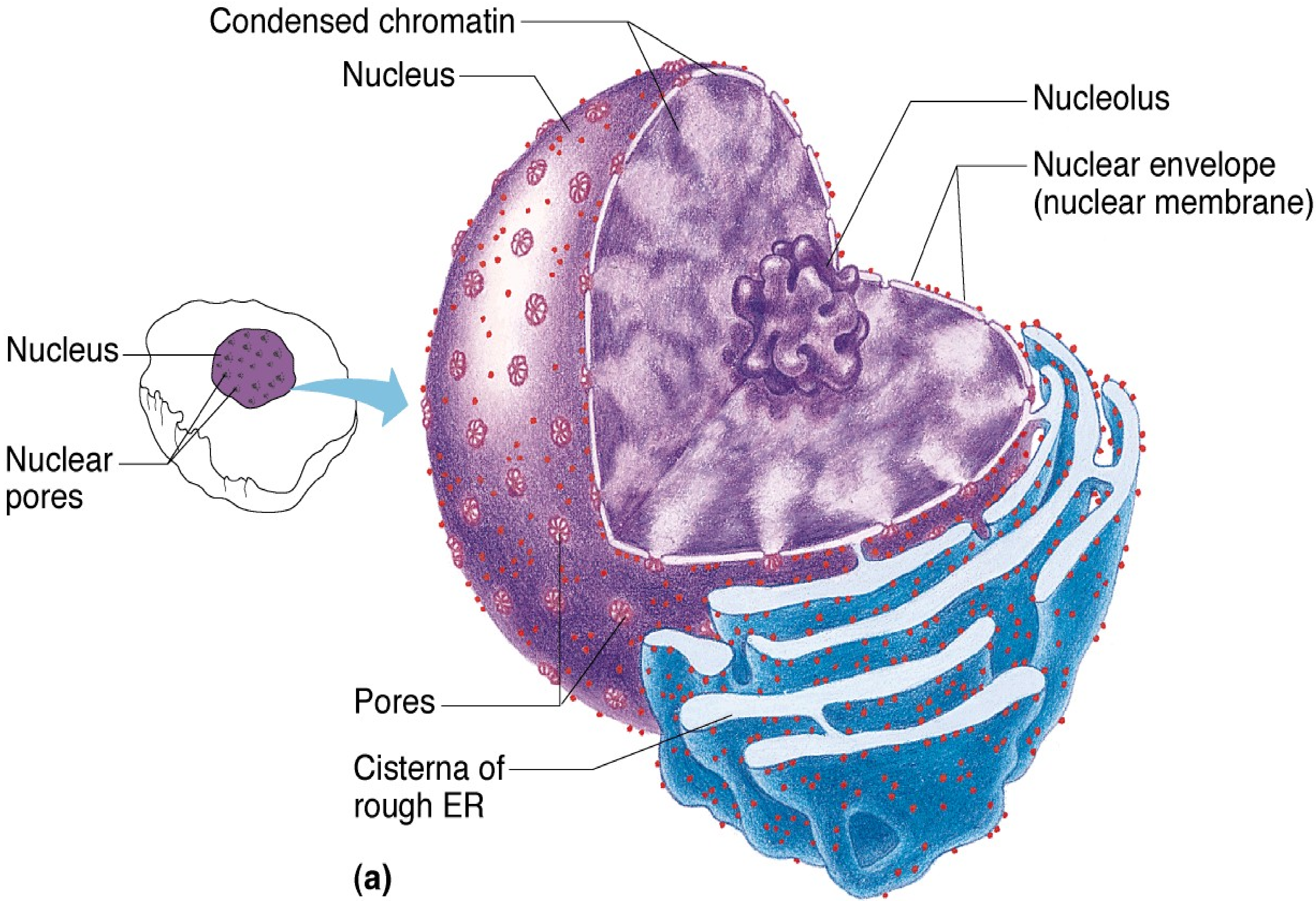
(a) Details of nucleus (b) Details of nuclear envelope



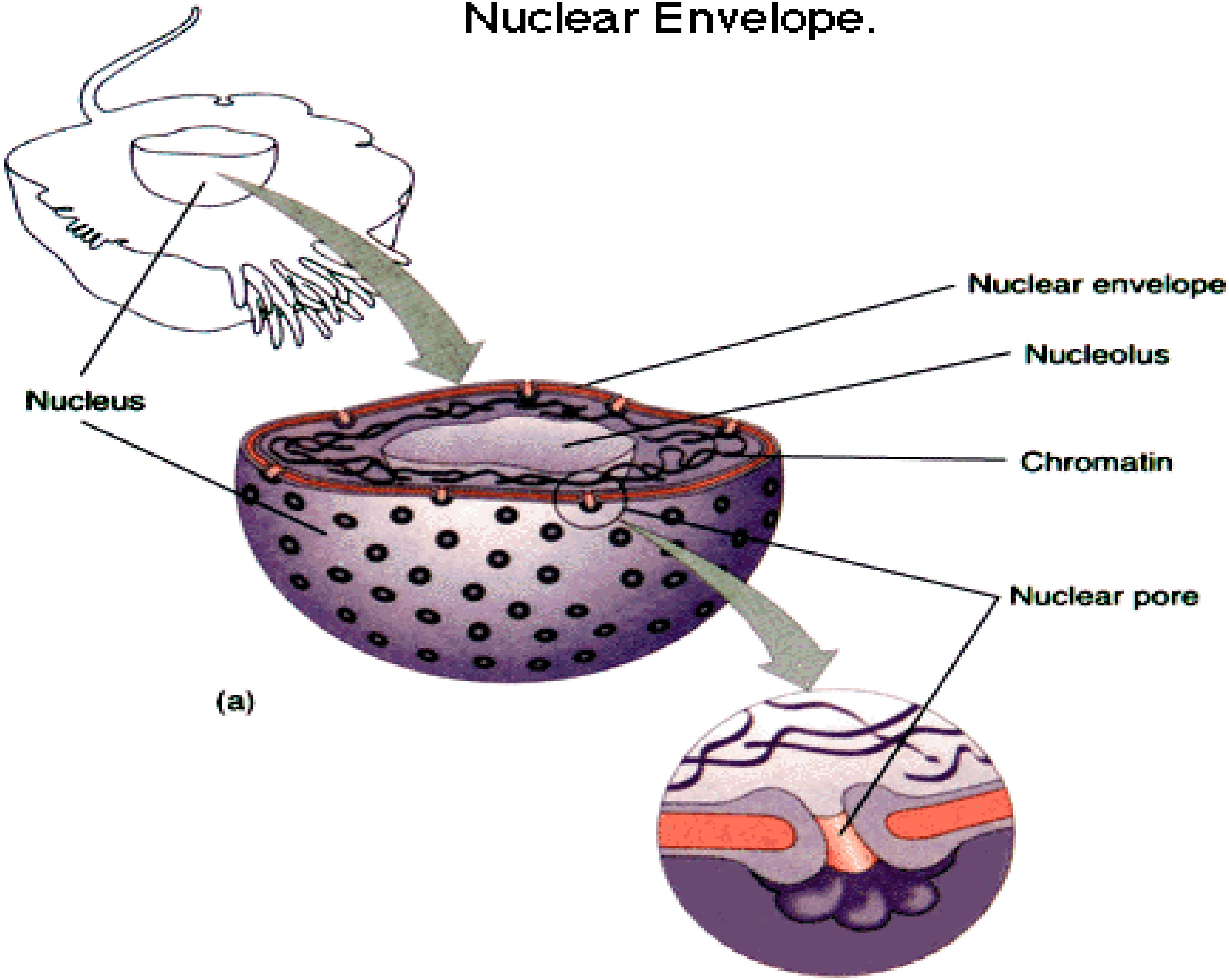
nuclear envelope
outer nuclear membrane
inner nuclear membrane
ER membrane
ER lumen
nuclear lumen
perinuclear space
nuclear pore
nuclear lamina

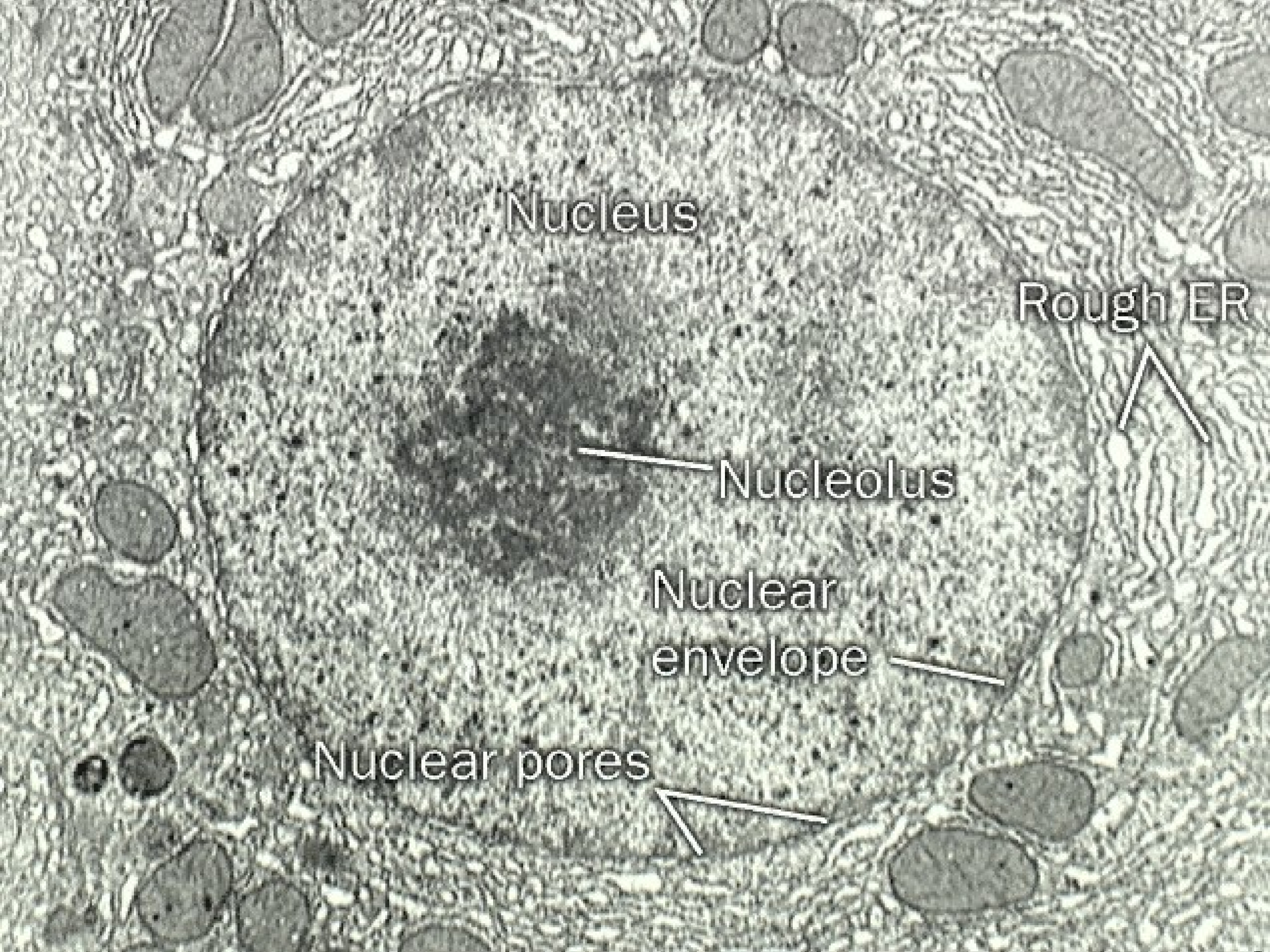

Chromatin
Nucleolus

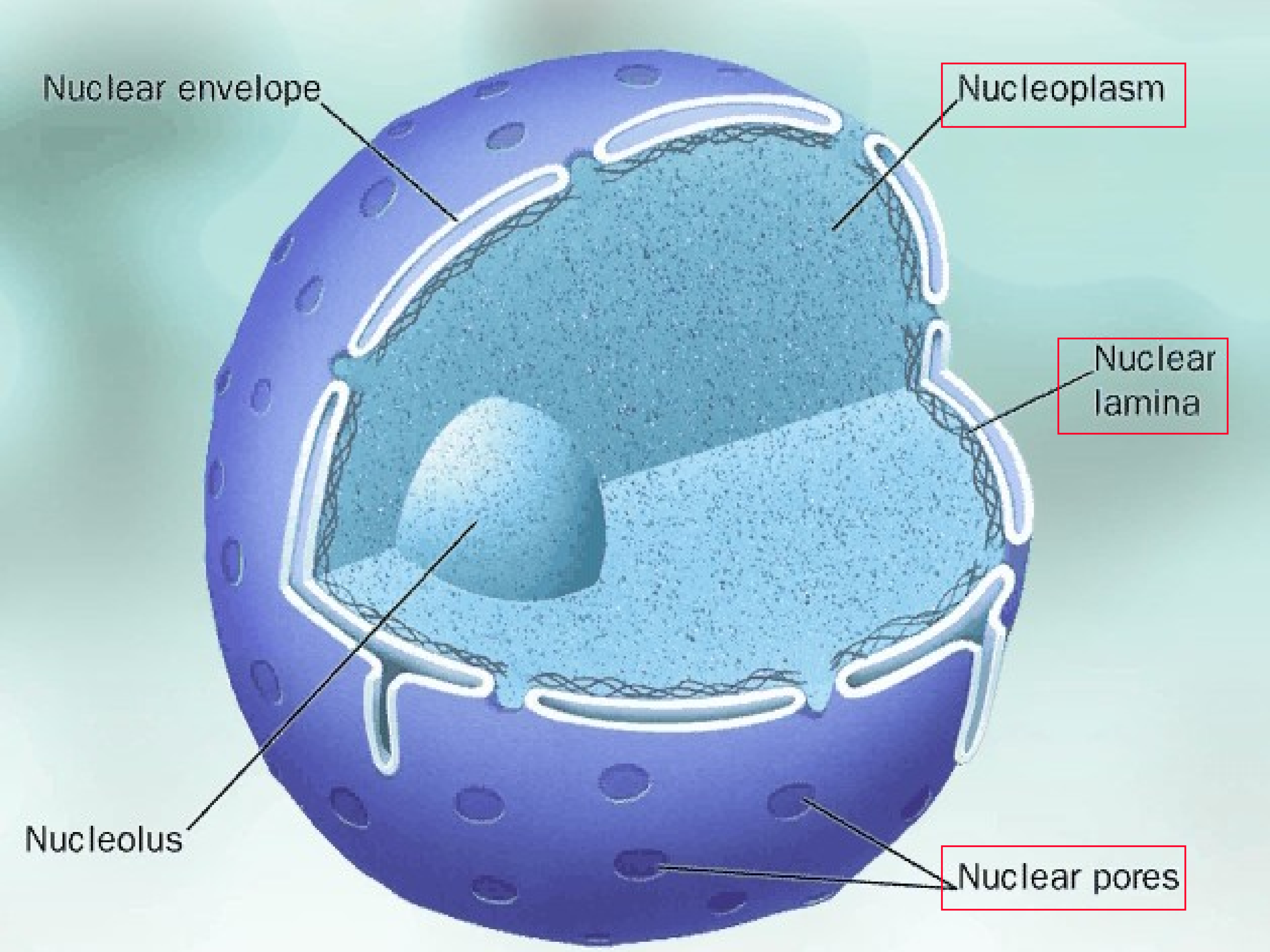

Nuclear pores
(heterochromatin)
Condensed chromatin
Nucleolus
Dispersed or extended chromatin
(euchromatin)
Nuclear envelope
Endoplasmic reticulum


Condensed chromatin
Nucleus
Nucleolus
Nuclear envelope
(nuclear membrane)
Nucleus
Nuclear
pores
Pores
Cisterna of
rough ER
(a)

Nuclear Envelope.

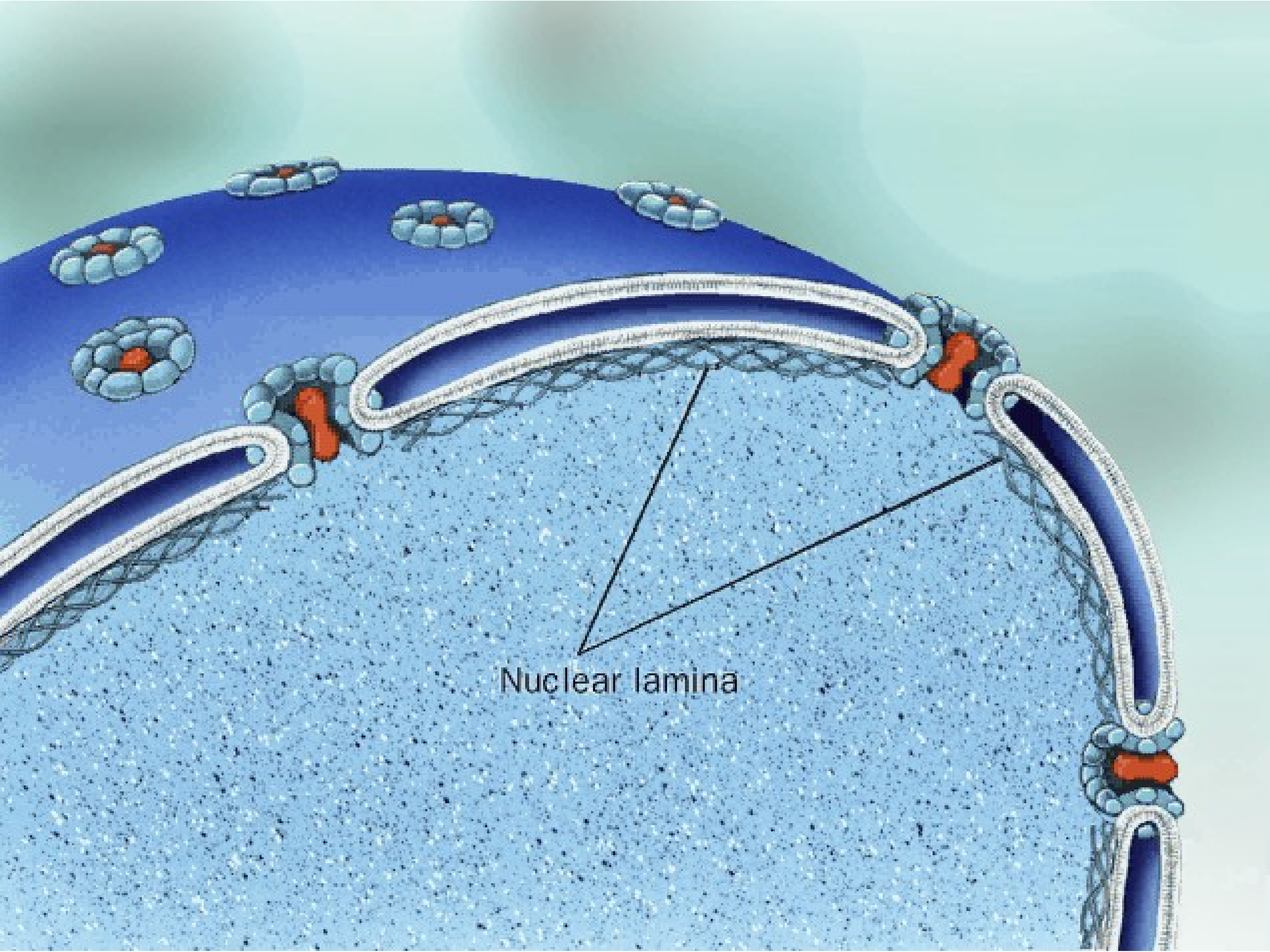



Nucleus
Rough ER
Nucleolus
Nuclear
envelope
Nuclear pores


Nuclear envelope
Nucleoplasm
Nuclear
lamina
Nucleolus
Nuclear pores

Nucleoplasm

Nucleoplasm is the fluid material within the nucleus. Chromosomes, nucleoli, and other particulate components of the nucleus, as well as the nuclear envelope, are distinct from the nucleoplasm.

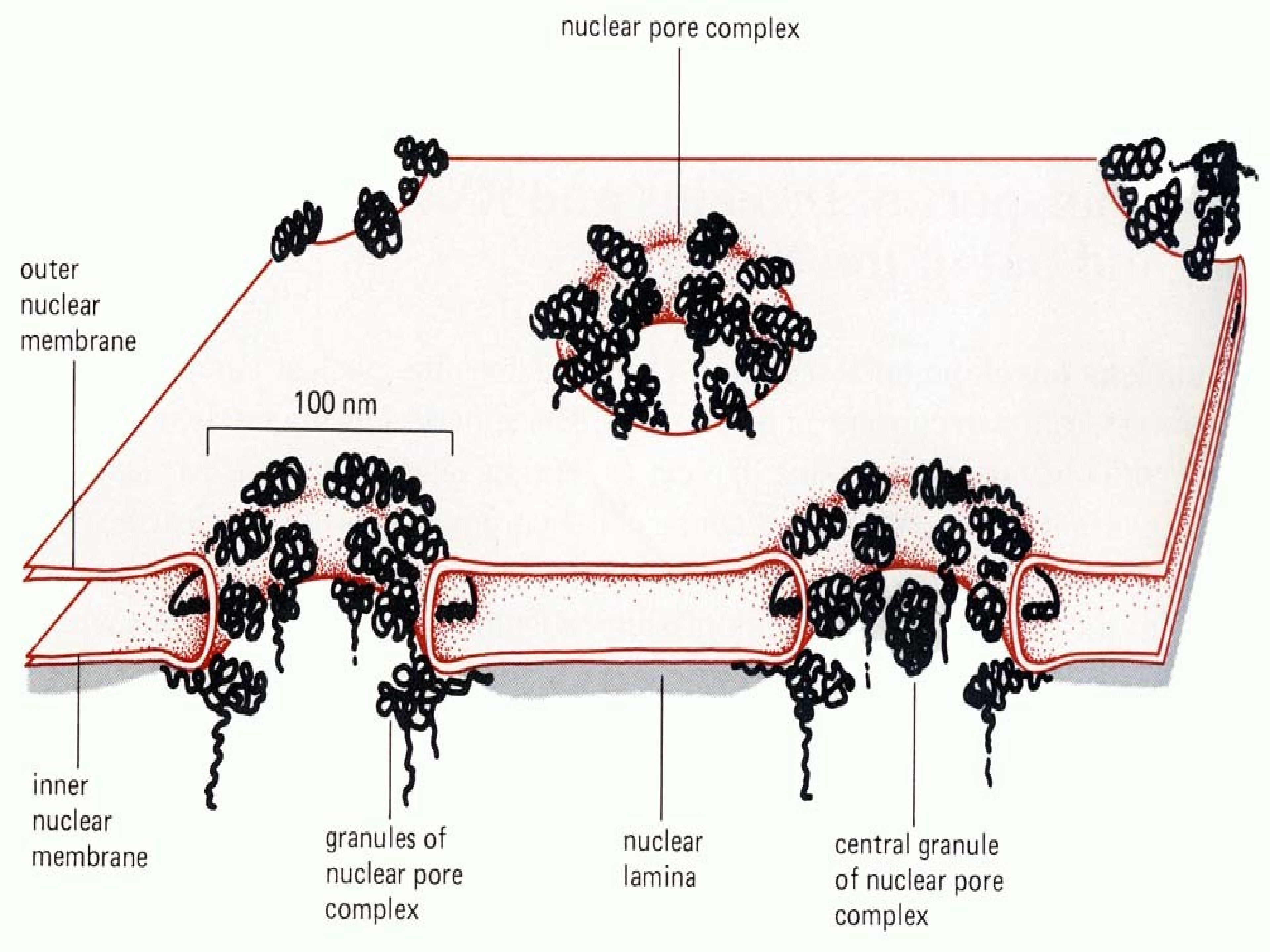

Nuclear lamina

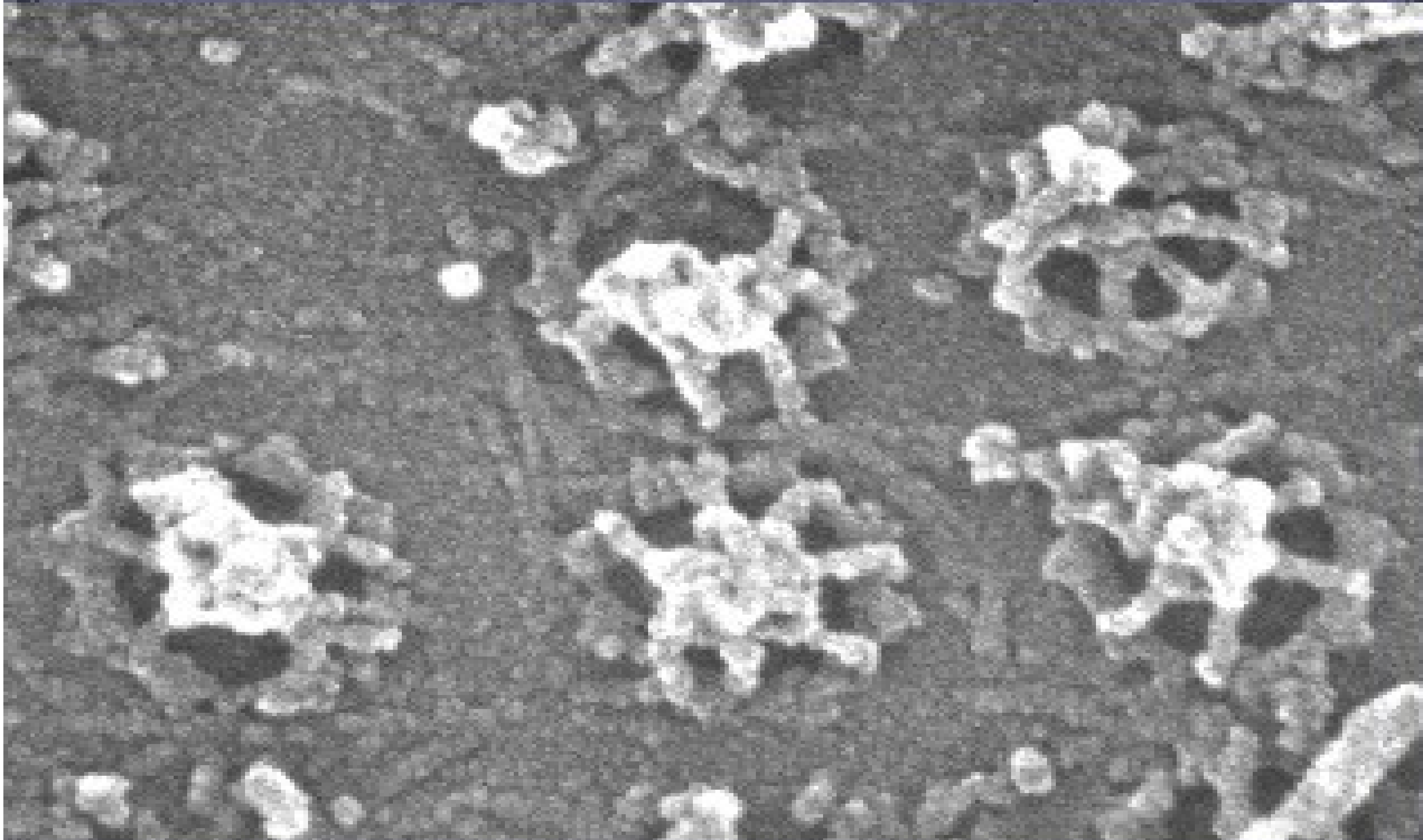
Nuclear lamina

In eukaryotes a nuclear lamina lines the inside of the inner membrane of the nuclear envelope. Intermediate filaments, woven together, constitute the nuclear lamina. These intermediate filaments are made of proteins called nuclear lamins. Breakdown of the nuclear lamina precedes the disappearance of the nuclear envelope at the start of prometaphase.

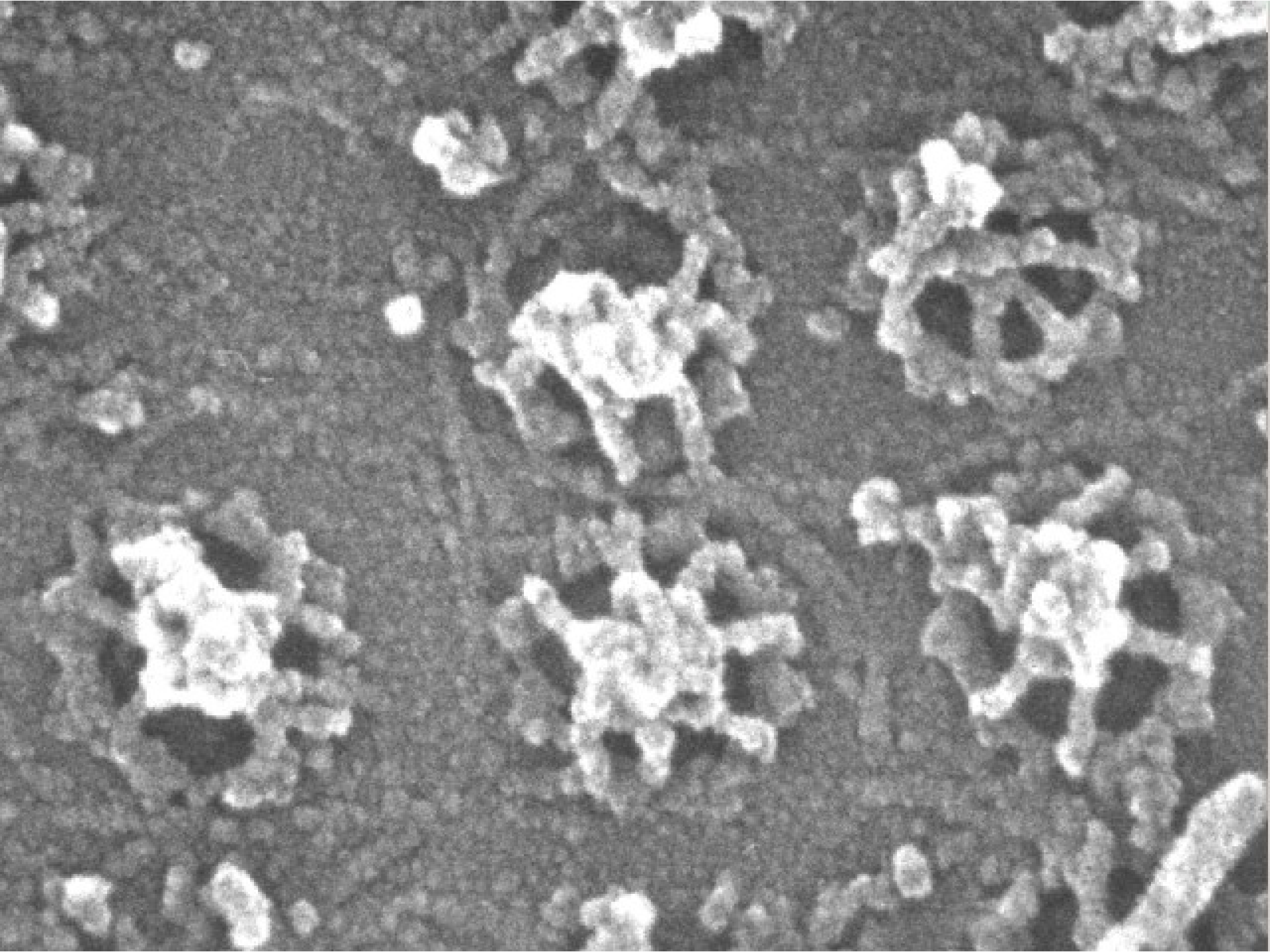
NUCLEAR PORES

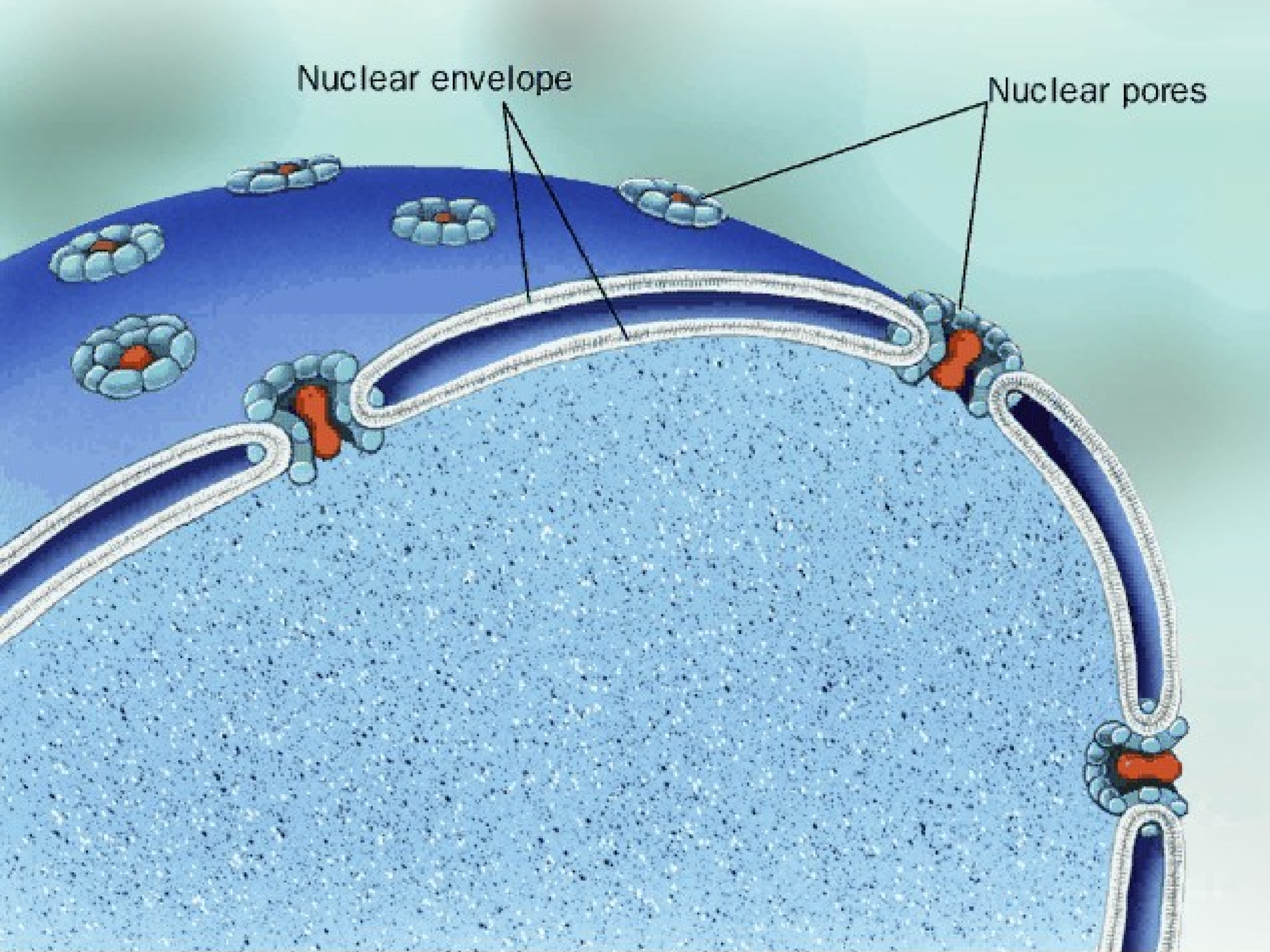
- The nuclear envelope is perforated by **nuclear pores – channels** that allow passage of certain molecules between the nucleus and cytoplasm.
- Each pore is part of the nuclear pores complex consisting of over a 100 different proteins.

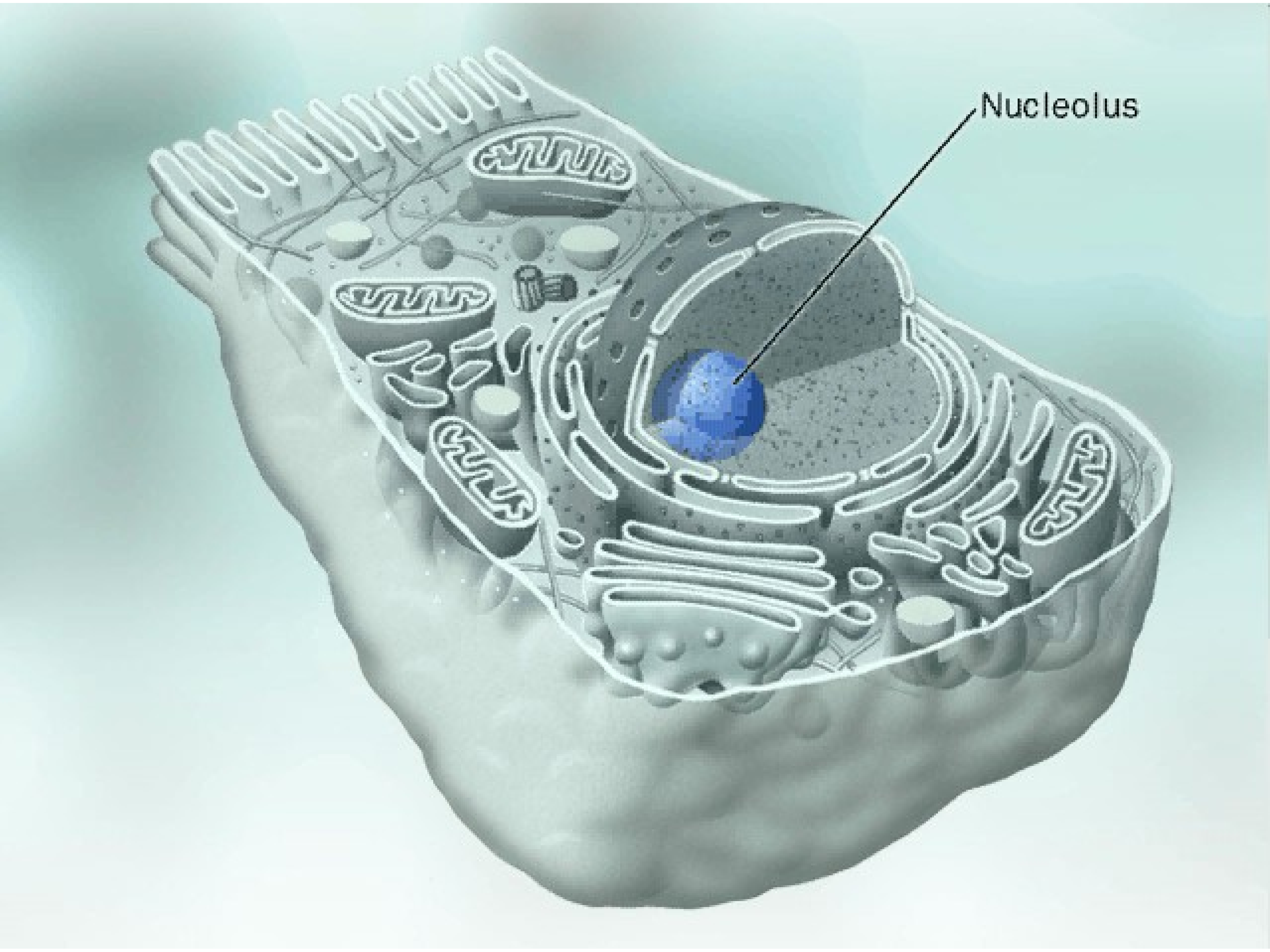

nuclear pore complex
outer nuclear membrane
100 nm
inner nuclear membrane
granules of nuclear pore complex
nuclear lamina
central granule of nuclear pore complex



Nuclear Pore Complexes. The structure of the nuclear pore complex is clearly seen in this scanning electron micrograph of the view from *inside* the nucleus. Each complex is made up of several proteins.

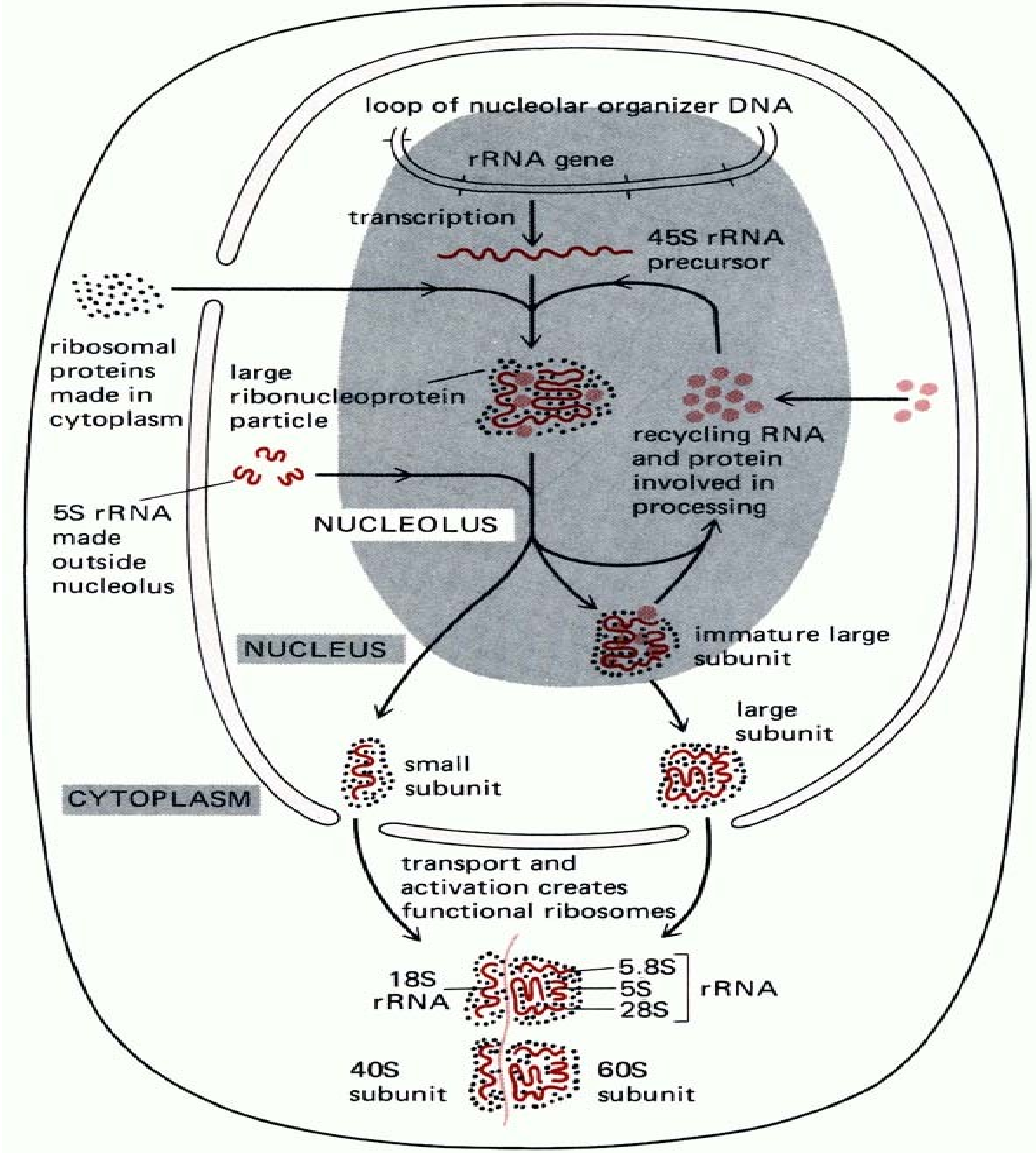



Nuclear envelope
Nuclear pores


Nucleolus

Nucleolus

A nucleolus is a small, generally spherical body found within the nucleus of eukaryotic cells. Transcription of ribosomal RNA (rRNA) takes place in the nucleoli, as does the assembly of ribosomal subunits. The nucleoli contain ribosomal RNA (rRNA) and many copies of the genes that encode rRNA. The number of nucleoli in a nucleus is characteristic of a species; one is the most common number.



loop of nucleolar organizer DNA
rRNA gene
transcription
45S rRNA precursor
ribosomal proteins made in cytoplasm
large ribonucleoprotein particle
recycling RNA and protein involved in processing
5S rRNA made outside nucleolus
NUCLEOLUS
NUCLEUS
immature large subunit
large subunit
small subunit
CYTOPLASM
transport and activation creates functional ribosomes
18S rRNA
5.8S
5S
28S
rRNA
40S subunit
60S subunit

EXTRACELLULAR MATERIALS

- These are substances contributing to body mass that are found outside the cells.
- One class is **body fluids:**
  - **Interstitial fluid**
  - **Blood plasma**
  - **Cerebrospinal fluid**

EXTRACELLULAR MATERIALS

- These are substances contributing to body mass that are found outside the cells.
- One class is **Body Fluids:**
  - **Interstitial fluid**
  - **Blood plasma**
  - **Cerebrospinal fluid**
- These fluids are important as transport and dissolving media.

EXTRACELLULAR MATERIALS

- Another class is **Cellular Secretions:**
  - **Intestinal and gastric fluids**
  - **Saliva, mucus, and serous fluids**
- These fluids are important in digestion and act as lubricates.

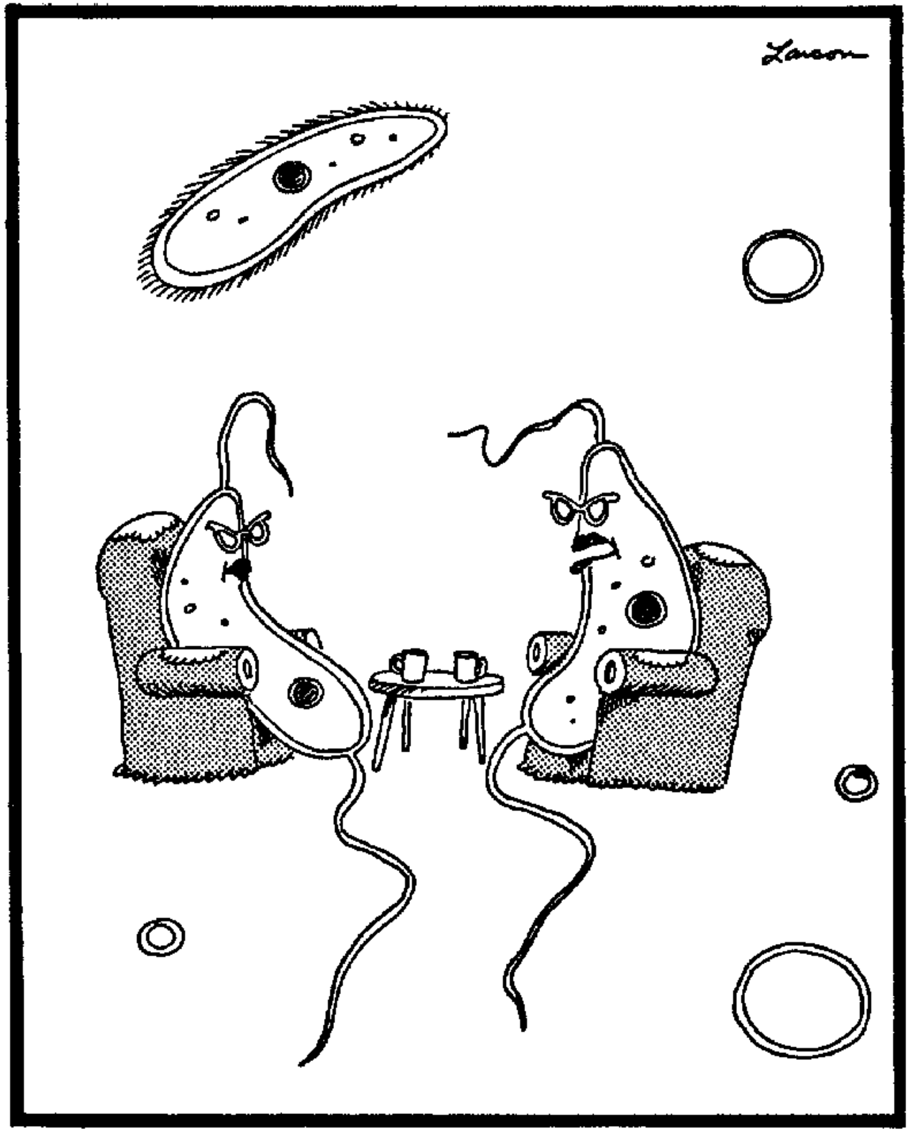
EXTRACELLULAR MATERIALS

- However the most abundant of the extracellular materials is the **Extracellular Matrix**
- Most body cells are in contact with a jellylike substance composed of proteins and polysaccharides.

EXTRACELLULAR MATERIALS

- This material is secreted by the cells and forms an organized mesh in the extracellular space where they serve as a universal “cell glue” that helps hold body cells together.

QUESTIONS



"He told you *that*? Well, he's pulling your flagellum, Nancy."